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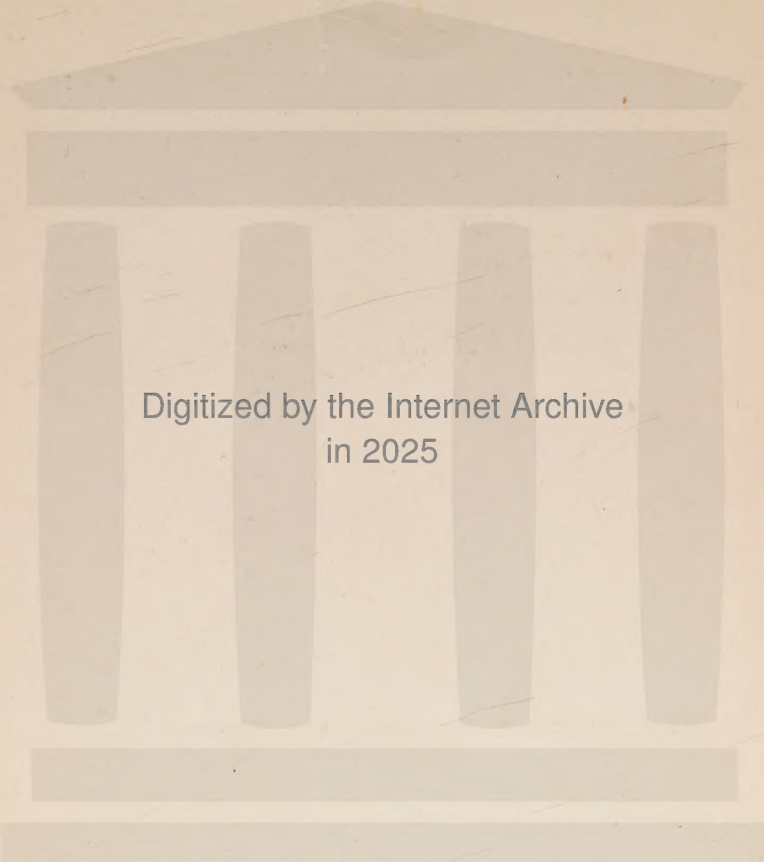
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BRAIN AND MIND
OR
THE NERVOUS SYSTEM OF MAN



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BRAIN AND MIND

OR

THE NERVOUS SYSTEM OF MAN

BY

R. J. A. BERRY, M.D., F.R.C.S., F.R.S., EDIN.

Dean of the Faculty of Medicine and Professor of Anatomy, Including
Histology, in the University of Melbourne; Honorary Psychiatrist
to the Children's Hospital, Melbourne, and Consulting Psy-
chiatrist to the Children's Welfare Department of the
Government of Victoria; Formerly Lecturer on
Anatomy in the School of Medicine of the
Royal Colleges, Edinburgh, and
Examiner in Anatomy to the
Universities of Aberdeen,
St. Andrews, Adelaide
and New Zealand.

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FOREWORD

1. "If psychology is to make any progress as a real science it must be a department of biology."

2. "The reëstablishment of the spiritual interpretation as the supreme interpretation of our universe is in no way inconsistent with the mechanistic interpretation of the living body."—*British Medical Journal*, page 387, March 3, 1923.

3. "If medical students are taught psychology it should be by a more real and vital psychology based upon behaviouristic, biological, physiological, psycho-pathological, and sociological foundations, and the teacher should be a medical man who has acquired a thorough theoretical and practical knowledge of these subjects."—Sir Frederick W. Mott, *British Medical Journal*, page 404, March 10, 1923.

4. "Neuronic insufficiency (as regards development, durability, or both) is the necessary antecedent of mental disease."—W. J. Shaw Bolton, "Archives of Neurology," Vol. II, 1903, page 505.

University of Melbourne,

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PREFACE

Availing itself of recent and intensive histological studies of the structure and function of the nervous system of man, by Golgi, Cajal, Bolton, Mott, Watson, Craig and others, this work is designed to show that the manifestations of the healthy mind result from combinations of brain cells, and that if from any cause whatsoever these cells are deficient in numbers, or are in an unhealthy condition, aberrations of the mind will probably result. With this object there is first discussed the general relationship of brain to mind, followed by a careful study of the unit of brain structure, the brain cell or neuron. The various combinations of neurons and their several functions are next dealt with in order from the simple to the complex. The sympathetic or autonomic nervous system is, from the standpoint of minute structure, the simplest portion of the nervous system, and is, therefore described first and not last, as in most modern works. The human brain, Nature's greatest masterpiece, is her most complex structural achievement, and is naturally described last. It is only by proceeding from the simple to the complex that the physician, psychologist, psychiatrist, or educationalist can hope to understand the phenomena of mind and their dependence upon structure. Having thus described the evolution, development, structure and function of the minute cells, of which the nervous system and brain are composed, a second part is added in which these truths of Nature are applied to the living man and woman. From the standpoint of the physician, there can be no disease which does not disturb the nerve cells concerned; hence it is important for these conducting nerve paths to be studied from the modern standpoint of the ingoing or receptive nerve impulses and the outgoing or effector ones. If the cause of the disturbance of these conducting nerves can

be ascertained or removed, the patient will be cured. If not, treatment merely diverts attention from the truth.

The great influence of education on brain growth, and therefore, on mind, is fully dealt with; and lastly those developmental conditions interfering with brain growth are discussed more fully than has hitherto been the case. It consequently follows that in individuals who pass on into the complexities of civilization with an imperfect or immaturesly developed brain are unable to react to their environment in the manner regarded as normal by normal people. Given the environment they may join the ranks of the anti-socials, or even degenerate into those more serious departures from structural normality which the Law regards as Insanity. Insanity is seldom a disease; it is rather an inability to react normally to a normal environment, and this inability is in many cases of purely physical origin, as are also many cases of criminality and prostitution.

An intimate acquaintance with some of the structural features of the human brain is thus seen to be not only necessary to the physician, but also to the psychologist, the educationalist, and the social worker. It is with these novel and complex problems that this work endeavors to deal. That many people are deterred from studying the structure and functions of the nervous system by its supposed difficulties is unhappily only too true, but so striking have been recent advances in the studies concerned, and all bearing on the phenomena of mind, that it is now certain that no one can any longer afford to ignore the structural details upon which all forms of mentality depend.

The concluding phases of the work comprise the practical applications of modern neurology to the living; and as these applications have been thoroughly tested out on about 15,000 individuals, it is not improbable that the psychologist, the psychiatrist, and the educationalist may find that a new and powerful weapon has been placed in their hands,—namely, the weapon of Truth.

RICHARD J. A. BERRY.

INTRODUCTION

The argument between Plato and Aristotle continues. The Vitalists viewing man as Energy, the Structuralists as a Machine, cannot yet compose their differences.

The notion describing each individual as a transformer of power is perhaps a compromise position truer than either. Around this general theme Professor Berry has written a stimulating, provocative, and doubtless controversial book,—one therefore to be urged on students that their vision may be widened, that they may be made aware of the three dimensional nature of the human nervous system—and that they may be led at least to suspect it of fourth dimensional qualities for the appreciation of which the requisite neuronic apparatus awaits development. Dreams though compounded of past experiences may be shot through with aspiration; the discontent of Man with himself and his works, forever scourging him upwards, cannot yet be seen with stains of gold and silver,—though this book makes clear enough the defects of structure which deny the expression and perhaps existence of such torturing impulses. We have here an attempt to correlate material with function; errors of material with errors of function. Its core is the dogma: no neurone, no mind—and beyond doubt the core is sound. The neurone, however, in its relation to mind is as the tap-root to the flower; knowledge of one is essential to knowledge of the other, but we must avoid seeing flower and tap-root as identical, as one and the same stuff. True, the seed must be finely natured by its parents and ancestors but, to flower in perfection it must be *nurtured* also; perhaps Professor Berry's emphasis on neuronic form as such tends to becloud somewhat his own demonstration that education is needed for the evolution of perfect neurones, and discipline and good habit for the mak-

ing of fine character. It is only slightly helpful to say that inadequate control of lower strata was exerted by the supra-granular cortical layer in Diana of Meredith's novel! Her upbringing and stock must both be weighed.

And we must remember there is a phylogeny of behaviour as of structure. The pressure of the instincts of hunger, sex, and the herd mould behaviour according to our inherited neuronic endowment. However, psychiatrists nowadays analyse too much the conflict of instinct with environmental stress and ignore variations in the instrument of life itself.

To give a juster viewpoint, this book has been written; in it is the tale of our painful climbing from the depths, of the building and controlling our powers of perception and adaptation,—and maybe from these neuronic origins spring man's nobility and lyric ecstasy as well.

At all events, my friend has wrought notably to depict the substantial workings of human faculties, he has shown their continuity with those of all living creatures, and he has made plain that control of human breedings must come before betterment in human brains. The broad strategic plan of mind is laid down in inherited neurones, in their number, quality and power to resist poison and fatigue, but the tactical details are worked in by stimulation, by social inheritance.

Lacking good endowment, education fails. Dr. Berry proves again that from sows' ears we can't make silk purses; in a world given to mental shortcuts, full of educational quackery and sentimental optimism he bids us to think straight and see clearly—Man, half brute, half angel, most wonderfully made in mechanism, whose spirit denies the Universe itself as boundary.

FOSTER KENNEDY.

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PART I
BRAIN AND MIND

BRAIN AND MIND

OR

THE NERVOUS SYSTEM OF MAN

CHAPTER I

BRAIN AND MIND

Introduction. The nervous system is the complex apparatus, the product of a long series of interesting evolutionary changes, by which the animal is brought into relation with its own bodily structure and the physical world around it, and by means of which it is enabled to react to its environment in the manner best suited to the requirements of its life.

Importance of the Study of Neurology. Every phenomenon of animal and human life is related to, and regulated by, the nervous system, and there are few diseases which do not manifest defects in its controlling influences, and yet there are few portions of the human body whose structure and functions are so little understood by the average practitioner as the nervous system. "The anatomy and physiology of the nervous system to many physicians and medical students is reminiscent of struggles with complicated parts of the body which seem to have little practical value. It has an established reputation based upon its difficulties rather than upon the advantages of understanding it." (Tilney and Riley.) It consequently follows that there are many who endeavour to study and teach the phenomena of mind, as well as its aberrations, who have little or no knowledge of the structure and functions of the human brain, and thus perpetuate error by constantly adding to it.

Brain and Mind. Between the primitive type of central nervous system, with its purposeful reflex unconscious actions, as seen in the earthworm, and the highly complex brain of man, with its manifestations of speech, thought, reasoning, delayed reaction to the stimulus, memory, and so on, there is an immense gulf. So much so, indeed, that it is not uncommon to find the human mind spoken of—especially by those with no knowledge of brain structure or its diseases—as though it were something which had no physical basis whatsoever, but was the result of a Psyche or soul, whereas the truth is that all mental phenomena are strictly dependable on physical construction, and that the elementary basis of such construction is always the neuron or nerve cell.

Basic Principles Underlying the Construction of all Nervous Systems. Every branch of study shows that the nervous system is, in all vertebrates, built up of a series of long conducting neurons, connected together by a series of shorter neurons. The former comprise the receptor (afferent or sensory) and effector (efferent or motor) neurons, the latter, the internuncial. Medical and clinical attention has for the most part been chiefly devoted to the *long conducting neurons*, because lesions therein are fairly obvious and of everyday occurrence. In the phenomena of mind and its aberrations, it is, however, the *shorter internuncial neurons* which are of supreme importance, and to these an insufficient amount of attention has been paid. It is in the human cerebrum that a sufficient number of neurons are found massed together and there are thus obtained those special reactions to the environment which we term “mind,” and yet, notwithstanding that in no part of the human body is function so strictly dependent upon structure as in the nervous system, the histology of the human cerebral cortex is, to the present-day student, a repellant subject, never understood, and to be forgotten as soon as the exigencies of examinations permit. It consequently follows that the medical profession imperfectly realises the importance of the correlation of cortical structure with mental function, and is thus at a disadvantage when

called upon to explain the phenomena of mind and its disorders and to associate these disorders with developmental and pathological errors, and yet all mental phenomena are really entirely conditioned by a highly complex system of neurons linked together in series of arcs.

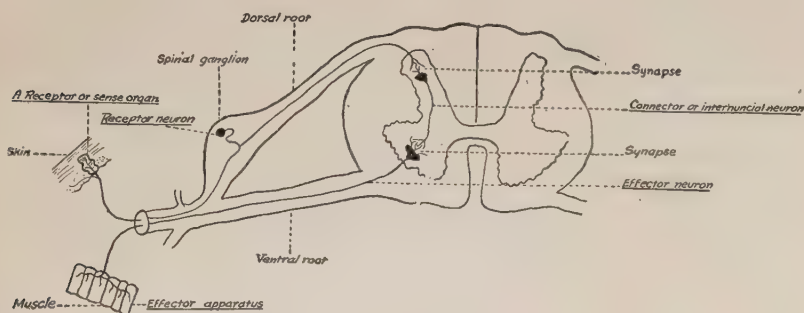


FIG. 1.—Structural elements of a neuron arc. See page 36.

Structural Elements of a Neuronic Arc. As the neuron will be fully considered later, it suffices to say that no nerve cell or neuron can function unless linked up with other neurons in the form of chains and arcs. A neuron arc, of the simple type found in the earthworm, consists of:

A sensitive receiving organ termed a *receptor* or sense organ. These are of very variable complexity of structure.

A *conductor*, that is, a receptor, sensory, or afferent neuron, which transmits the stimulus received in the form of nerve impulse in an inward or central direction.

One or more short adjustor or *connectant* internuncial neurons, usually limited to the grey matter of the nervous system, and found, in the case of the earthworm, in the neuropile of each segment, and in the case of man, in very large numbers in the association areas of the human brain.

A second *outward conductor*, that is, an effector, motor, or efferent neuron, which transmits the nerve impulses in an outward, or peripheral, direction to

The *effector apparatus*, which comprises the muscles,

glands, or other organs of response, and in or upon which the effector neuron terminates.

In the earthworm the foregoing elements of a neuron are present in every segment. The receptor or sense organ is found in the cuticle. When suitably stimulated it causes the receptor neurons to generate nerve impulse which affects the connectant neuron within the neuropile. This, in its turn, arouses the effector neuron to a discharge of nerve impulse and so the effector organ is stimulated to action. There is thus a direct reflex response to the original stimulus, and such an action is an *unconscious purposeful reflex action*. Stimulation applied to the receptor element of any one segment of the earthworm does not, therefore, arouse consciousness. It simply produces a purposeful reflex response to a simple stimulus. The purposive character of this reflex action, as seen in the earthworm, or as obtained experimentally in the spinal frog, has sometimes led to the belief that such animals—spinal cord animals—have a guiding intelligence. “At the present time we recognise that every reaction of a living being must be purposive, in the sense of being adapted to the preservation of the species, if the latter is to survive in the struggle for existence. The question as to whether we are justified in predicating the existence of even a germ of consciousness or volition in the spinal animal must be decided in the negative.” (Starling.) As Sherrington expresses it, “where even simplest ideas are not, there cannot be consciousness.” Consciousness then, like all mental phenomena, primarily depends on a relative sufficiency of neurons at the cephalic end of the neural tube, in which the memories of previous receptor impulses may be stored up, and these the earthworm does not possess.

In the common earthworm there is no “brain” whatsoever. The so-called “end-brain” of the earthworm is merely a fusion of certain ganglia which dominate the local activities of the several segments, and enable the animal to react, as a whole, to the external and internal bodily stimuli, but the histological

CENTRAL NERVOUS SYSTEM SEGMENTED WITH THIS TYPE OF NERVOUS SYSTEM INSTINCT, I.E., AN INVARIABLE BEHAVIOR PREDOMINATES		CENTRAL NERVOUS SYSTEM SUPRASEGMENTAL IN CHARACTER, WITH THIS TYPE OF NERVOUS SYSTEM REASON, I.E., A VARIABLE OR INDIVIDUALLY MODIFIABLE BEHAVIOR PREDOMINATES						
	SPINAL CORD	RHOMBENCEPHALON MEDULLA OBLONGATA, PONS.	MIDBRAIN	DIENCEPHALON THALAMOSTRIATE BRAIN	ARCHIPALLIUM	INFRAGRANULAR CORTEX	TELENCEPHALON SUPRAGRANULAR CORTEX	ASSOCIATION AREAS WITH BOTH SUPRAGRANULAR AND INFRAGRANULAR CORTICES
ANNELIDA <i>EARTHWORM</i>	REFLEX ACTIVITIES ONLY							
CYCLOSTOMATA <i>SEA LAMPREY</i>	REFLEX ACTIVITIES	BRAIN OF VITAL REFLEXES	BRAIN OF CO-ORDINATION					
TELEOSTEA <i>BONY FISH</i>	REFLEX ACTIVITIES	BRAIN OF VITAL REFLEXES	BRAIN OF SIGHT	BRAIN OF CO-ORDINATION				
REPTILIA <i>ALLIGATOR</i>	REFLEX ACTIVITIES	BRAIN OF VITAL REFLEXES	BRAIN OF SIGHT	BRAIN OF CO-ORDINATION AND OF PRIMITIVE EMOTIONS	SMELL			
MAMMALIA <i>DOG</i>	REFLEX ACTIVITIES	BRAIN OF VITAL REFLEXES	LIGHT AND OTHER REFLEXES	LOWER CEREBRAL FUNCTIONS	SMELL	BRAIN OF CO-ORDINATION AND OF PHYSICAL FUNCTIONS		
SIMIIDAE <i>APE</i>	REFLEX ACTIVITIES	BRAIN OF VITAL REFLEXES	LIGHT AND OTHER REFLEXES	LOWER CEREBRAL FUNCTIONS	SMELL	BRAIN OF CO-ORDINATION AND PHYSICAL FUNCTIONS		
HOMINIDAE <i>MAN</i>	REFLEX ACTIVITIES CONDUCTION	BRAIN OF VITAL AND OTHER REFLEXES	SPECIAL SENSE REFLEXES	THALAMUS AND STRIATE BODY CONTROLLED BY PALLIUM CORTEX	SMELL MUCH REDUCED	BRAIN OF CO-ORDINATION AND PHYSICAL FUNCTIONS CORTEX OF THE SELF-PROTECTIVE, SEXUAL AND OTHER ANIMAL FEELINGS	CORTEX OF CONTROL AND EDUCABILITY	CORTICES OF THOUGHT, REASON, SPEECH, AND HIGHER MENTALITY

Fig. 2.—A scheme to show how successive additions of neurons at the cephalic end of the neuralis, and a shifting forward of function gradually produce a brain of mind, reason and speech.

construction of this "end-brain" of the earthworm does not differ, structurally, from that of the neuropile of the segments, except in so far as it contains a larger number of integrating and connectant internuncial neurons.

Lastly, it is important to note, as will be fully described later, that the component nerve elements of the neuron arc are structurally discontinuous. There is a break, termed the *synapse* or *neuro-synapse*, which the nerve impulse has to cross, or rather the nerve impulse has to overcome the resistance of this break before it can arouse the next nerve element in the chain or arc to generate and discharge its energy.

Specialisation of Internuncial Neurons. It has already been seen that, in their simplest form, internuncial neurons are apparently simple connectors between the receptor and effector neurons of the arc. As increasing functional demands are made upon the nervous system in accordance with the increasing rises in animal intelligence, from purposeful unconscious reflex actions, to complete voluntary and conscious control over these actions, that is, the power of delaying or inhibiting the effector responses to the incoming receptor stimuli, the internuncial neurons not only increase in numbers and complexity of connections, but begin to be specialised for special purposes, such as correlation, association, and integration. These increments in the numbers of the internuncial neurons chiefly occur in the supra-segmental portions of the neuraxis and particularly in the cerebellum and cerebrum, that is, at the cephalic end of the neural tube.

Transitional Animal Types Between the Earthworm and Man. That there is an immense gulf between the primitive nervous system of the earthworm and the complex brain of man, both structurally and functionally, is perfectly obvious. What is not so well known, though it is equally obvious, is that this gulf, as regards the nervous system, is bridged over by living and intermediate animal forms, and in such a convincing manner as to leave no room for doubt that neurons

in combinations of arcs, with a constantly increasing complexity of internuncial neurons, are the physical basis of all intelligence and mind in the animal kingdom, and that disease, or developmental absence, of functioning neurons is the neurological key to many disorders of mind.

If the central nervous system of such living animal forms as the earthworm, sea lamprey, teleostean fish, alligator, dog, anthropoid ape, and man, be regarded in series, it will be observed that there is continually being added to the cephalic end of the neuraxis additional numbers of neurons linked together in series of arcs, and that these neurons are developed within the successively developed cerebral vesicles. The last one of these to be added in each animal form constitutes the "end-brain"—an unfortunate and somewhat misleading term because it does not follow that the end-brain of one animal is the same as the end-brain of a higher animal. In fact it is not. The end-brain of man is not the same as the end-brain of the reptile, for example, nor is the end-brain of the reptile the same as that of the earthworm. As each of these new end-brains is added on to the neuraxis there is a shifting forwards to it of the functions previously undertaken, if at all, by the earlier "brains" of the neuraxis, and the last one to be added assumes control over all the older ones. This process of shifting forwards of cerebral function to a newly added end-brain is known as *telencephalisation*. In every instance the histological construction of these evolutionary additions to the cephalic end of the neuraxis always involves an increase in the number and complexity of the internuncial neurons, so that comparative anatomy, embryology, and histology all compel the conclusion that no matter what may be the behaviour of the animal to its environment the physical instrument is always the neuron.

Cajal's Five Epochs of Neuronic Arcs. Every living animal reacts to its environment in accordance with the structural evolution of its nervous system, and from the evolutionary standpoint Cajal has pointed out that the neuronic arc seems to have passed through five great epochs, as follows:

The epoch of irritability.

The epoch of the reflex arc.

The epoch of the intersegmental reflex neuron.

The epoch of the suprasegmental reflex neuron.

The epoch of the psycho-associational neuron.

The *epoch of irritability*. In the porifera or sponges a stimulus, chemical or physical, is received by a receptor cell on the surface of the organism thereby causing an adjacent effector or motor cell to contract in response to the stimulus,

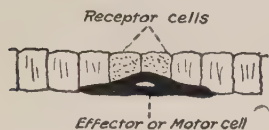


FIG. 3A.—Epoch of irritability.
See pages 783, 444.

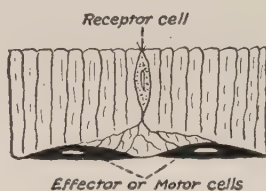


FIG. 3B.—Epoch of the reflex arc. Sea anemone.
See page 8.

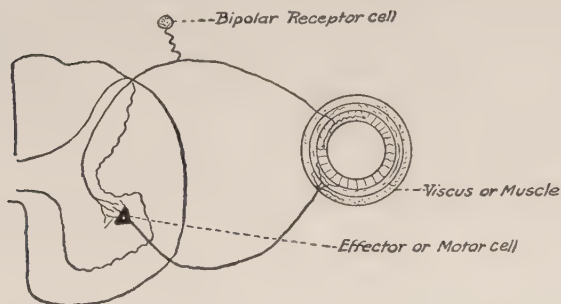


FIG. 3C.—Epoch of the reflex arc. Man. See pages 8, 36, 444.

and so the organism adapts itself to the environment. Simple contractile cells of this nature form the primitive basis of the nervous system of all animals, man included, and the stage—the epoch of irritability—is the earliest form of a conducting nervous system. In this type there is no junctional tissue between the receptive cell and the effector, hence, when the former is stimulated there is an immediate local reaction and the exact nature of the response to the stimulus can be predicted with certainty and will always be of the same type.

if this form of neuronie epoch be present in man it is most likely that the myenteric reflex represents it. (See page 83.)

The *epoch of the reflex arc*. In the coelenterates, as, for example, the sea anemone, the receptor stimulus from a limited area of reception is transferred, through a neuronie reflex arc of the very simplest type, to an extensive area of reaction. This stage, in which several parts of the body may be made to react in response to a single stimulus, constitutes a very significant forward advance in the evolution of a nervous system. One cell becomes specialised for the reception of impulses, and another for their transmission to the organ of response. The former eventually develops into the receptor neuron and the latter into the effector, whilst the two together form a simple neuronie reflex arc, which is the structural basis of all nerve phenomena, mind included. The patellar reflex of man is said by some authorities to be over a two-neuroned arc as here described.

The *epoch of the intersegmental reflex neuron*. When the animal body becomes definitely segmented, as in the earthworm, there is a further development, which assumes the form of a new neuron interposed between the receptor and effector elements of the arc, which has now two breaks or synapses, in its continuity, instead of only one as in the two-neuroned reflex arc. This new element in the arc may be termed the *internuncial neuron*. Neurons of this type are, in the earthworm, found in the neuropile and the head ganglia, and the synapses between the receptor and connector, and again between the connector and the effector neurons permit of the branching discharge of nerve impulse. In this way the reaction may be confined to the segment concerned, or the impulses may be transferred to the head ganglia where all are co-ordinated. Neuronie arcs of this type are very common in the human spinal cord.

The *epoch of the suprasegmental reflex neuron*. In all segmented animals, such as most vertebrates lower than the

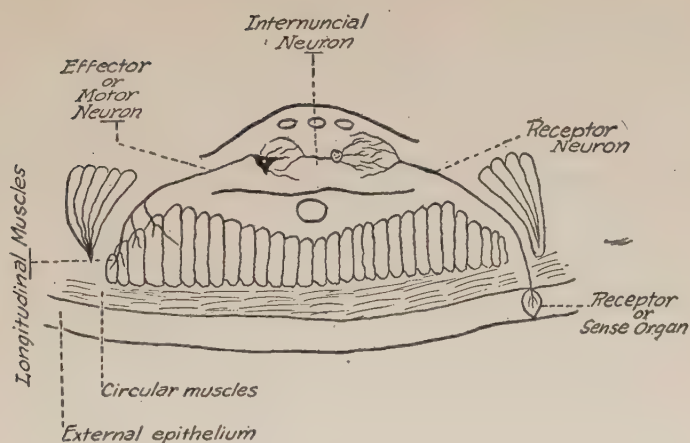


FIG. 4A.—Epoch of the intersegmental reflex neuron in the earthworm. See page 8.

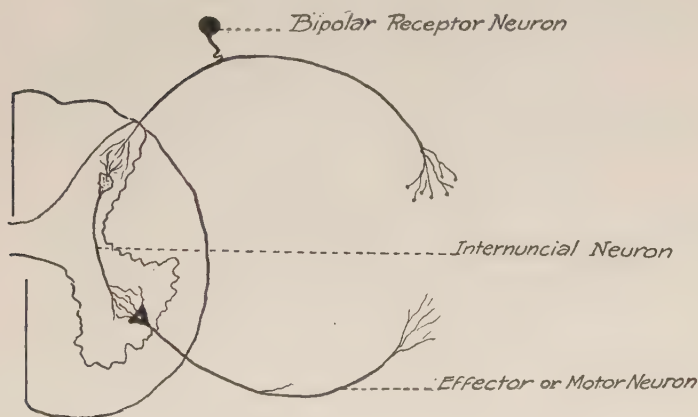


FIG. 4B.—In man. See pages 8, 37, 122, 129, 440.

mammal, the reflex arc and the intersegmental internuncial neuron suffice to regulate the motor reactions in the behaviour of the animal. All the bodily motions are immediate responses to the stimulus, that is, they are reflex actions, consequent on the translations, without any delay, of receptor stimuli into motor or effector responses. In all such animals

the behaviour will be in strict accordance with the stimulus. Further, the combinations of these stereotyped performances will be limited in their scope, and rigid in their form.

Up to this time in the development and evolution of a nervous system, there is no appreciable interval between the receipt of a stimulus and the despatching of the motor or

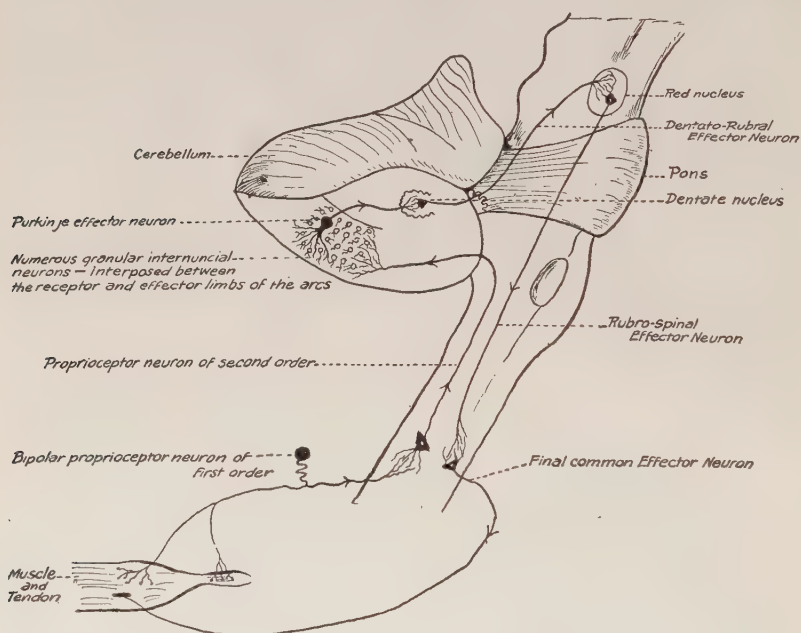


FIG. 5.—The epoch of the suprasegmental reflex neuron.
See pages 8, 129, 445.

effector impulse, so that the reflex act has an immediate consummation in motion. In the higher animals such immediate response to the stimulus would often be disadvantageous to the animal's welfare, and it becomes, therefore, essential to the well-being of both mammals and man to have a period of latency between the receipt of the stimulus and the motor reaction. This pause in the reflex action, this *period of latency*, furnishes an interval, as it were, for reflection, and allows of a selection of the most advantageous motor reaction. This is essentially the first step in introducing a more

plastic type of behavioural reaction. The new element which so produces the period of latency, by holding in check the effector response to the stimulus, until the most favourable moment has arrived for its accomplishment, provides the important factor of *inhibition*, which has attained its highest development in the brain of the normal man. The neuronc machinery by which this is brought about consists in the addition of an enormous number of supra-segmental neurons collected together into the most recently added end-brain. When this epoch has been reached, that is, the *epoch of the supra-segmental reflex neuron*, the nervous system has clearly come under the guidance of a new influence and has acquired the far-reaching quality of being able to withhold action until it is most opportune and profitable. Behaviour is thus no longer a matter of instantaneous impulse, but is made subject to a certain degree of supervisory review, guided by a primitive form of judgment which may be taken to mark the beginning of psychic life.

The *epoch of the psycho-associational neuron*. The final

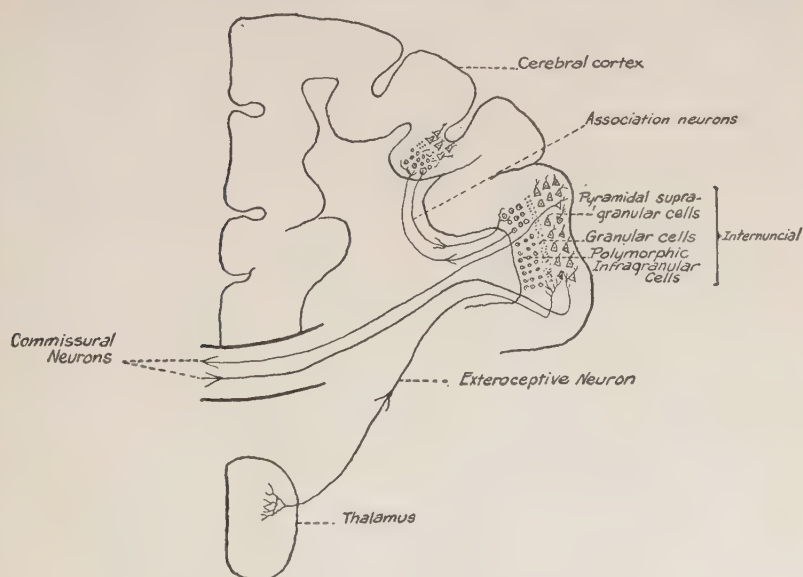


FIG. 6.—The epoch of the psycho-associational neuron.
See pages 11, 130, 353, 354, 356.

step in the centralisation of the nervous mechanism, enabling it to attain the consummation of its functional capability, is reached with the addition of the psycho-associational neurons, and attains its highest development in man. By this means, that is, by an enormous addition of cortical neurons in association areas, numerous associations are made possible between the various types of sensibility, including somæsthetic sense, vision, hearing, taste, and smell, out of which the individual is constructed and upon which the foundations of all the higher faculties rest. (Tilney and Riley.)

Logical Deductions from Brain Structure. Every branch of study thus forces upon us the inevitable and only logical conclusion that the neuron, particularly the short interpolated or internuncial neuron, is the physical instrument of mind, but that consciousness, memory, speech, thought, and reason, can only manifest themselves when there are a sufficiency of such neurons for the purpose. If, in the human being, in whom it is estimated there are 9280 million neurons in the cerebral cortex, these neurons should be deficient from developmental or other cause, there are inevitably produced aberrations of intelligence and mind, with corresponding alterations in the reactions to the environment, that is, the behaviour of the individual becomes modified in accordance with the cortical development of his neurons.

Other Factors in the Production of the Manifestations of Mind. Although stress has very properly been laid upon the importance of the neuron or nerve cell in all mental phenomena, it is not to be assumed that there are no other factors concerned besides the mere number of neurons. Amongst these may be mentioned the state of development and physiological condition of the neurons, the number and nature of the receptor impulses transmitted over these neurons to the central nervous system, that is, the environmental factor, and the potential energy developed by the neurons.

"One of the most striking characters of the neurons (neuroblasts), at all events in the higher vertebrates, is that, contrary to the cells of other organs, the whole of those which the

adult animal is to possess are present at birth, gradually taking on functional activity. There is no evidence of any regeneration after destruction or death of any individual neuron." (Bayliss.) "In the case of medullated nerves, the *acquiring of the fatty or medullary sheath* is the sign that the neuron is ready to transmit impulses." (Harris.) Without that sheath the neuron will not transmit impulses, nor will it do so if it remain in the embryonic neuroblastic condition, that is, until development is completed the neuron cannot function. It is not sufficiently realised that in some individuals many of the cortical neurons, particularly those of the psycho-associational type, remain permanently in this undeveloped embryonic condition throughout life, with a corresponding alteration in the reactions to the environment.

Notwithstanding that little is certainly known as to the functions of the myelin sheath in medullated nerve axons, it appears to be certain that myelination is essential to a correct and normal functioning of the central nervous system, as opposed to the autonomic or visceral nervous system where many of them remain in the non-myelinated condition. But the Anatomist is not unmindful of the fact that the whole of the white medullary centre of the cerebral hemisphere is entirely made up of many million myelinated association, commissural, and projection fibres, all lying in the closest juxtaposition, and he asks himself, supposing those fibres should remain partially undeveloped, that is, only partially myelinated throughout the whole of life, can there be a normal mental functioning of the brain? Is it not more reasonable to suppose that, under such conditions, the nerve impulses will undergo a certain amount of dissipation before arriving at their correct destination and so give rise to hysterias and other mental conditions characterised by irresponsible reaction to the environment, because as Starling says, the main nerve tracts cannot be shown to be functional before the date at which they acquire their medullary sheath.

Again, the importance of temporary or permanent exhaustion of the nerve cells, that is, *chromatolysis*, in altering the

mental reactions is not sufficiently realised. Every medical man is aware of the profound mental disturbances produced in the high temperatures of fevers, but forgets apparently that the underlying cause—chromatolysis—is brought about by many other factors besides those of fever temperatures, and may equally well be followed by abnormal mental reactions. In the normal mental functioning of the nervous system, the physiological condition of the neuron is, therefore, obviously a very important matter.

Sherrington's work has familiarised most medical men with the *incoming to the brain* of entero-ceptive impulses from the viscera and internal bodily world generally; of proprio-ceptive impulses from tendons, muscles, joints; and extero-ceptive impulses from the external world around us, but whether the real significance, and profound influence of these impulses on brain structure and the manifestations of mind, are equally well understood, is another question. As Flack and Hill remark, "extero-ceptive, proprio-ceptive, and entero-ceptive impulses stream into the central nervous system from the time of its embryonic development until death, ceaselessly modify the pattern of its structure, lay down the pathways of reflex actions, and establish habits." That splendid instance of scientific observation and logical deduction, Dr. J. S. Bolton's "The Brain in Health and Disease," contains many examples of actual neuronie alteration in brain structure, and therefore in mentality, as a result of deprivation of incoming receptor impulses. Most of us who are called upon to study the aberrations of the human mind are fully and painfully aware of the fact that "in the case of children deprived of the senses of hearing and vision from birth there results the condition known as idiocy from birth from deprivation of the senses. They experience fewer sensations than healthy children and are therefore mentally deficient, and have fewer fully developed cortical neurons." No explanation of the emotions, passions, and moods, or of their appropriate motor or effector responses or inhibitions can be accepted, which is not equally

applicable to all living animals in accordance with their position in the evolutionary scale and the conditions of their nervous systems. Such explanations must be further applicable to all conditions of health and disease under which those emotions are displayed, and here non-biological Psychology is apt to fail. Its explanations often forget or ignore these essentials, and its exponents almost equally invariably introduce their own personality into that of others. One's own individuality is compounded of one's own neuronie development and one's own receptor impulses, and it is quite frankly impossible to believe that these are the same in any two individuals and hence no two human beings have precisely the same detailed outlook on life or the same "mind."

What Is Nerve Energy? Just as the Physicist uses the term gravity to denote a force which he can measure, and the influence of which he can observe, but of whose nature he knows little or nothing, so has the Neurologist to employ the term *nerve impulse* or *nerve energy* to denote a phenomenon of which he knows little beyond its observable effects, and yet there are many nervous diseases, where it is not improbable that, consequent on alterations in the neuronie systems, there is an altogether abnormal and irregular discharge of nerve energy.

It is very important to remember that the elements of a neuronie arc are, certainly in all higher vertebrates, structurally discontinuous, that is to say, there is a break between any two of the several nerve elements, termed a *synapse* or *neuro-synapse*, the resistance of which has to be broken down before the energy generated by one neuron can affect the next in the chain. Nerve cells are constantly generating, receiving, or storing up nerve impulses (Tilney and Riley) and the innumerable synapses offer many possibilities for branching discharge and variations in the neuronie arcs traversed. If the nerve impulses involve aberrant arcs, that is, arcs which should not normally be affected, it necessarily follows that aberrant phenomena follow, and this is particularly applica-

ble to the human cerebral cortex which contains more neurons and more synapses than any other portion of the nervous system, hence the destruction of some cortical neurons in the normal arcs will be followed by abnormal mental phenomena.

The Cerebral Cortex. The mammalian cerebral cortex is built up on an infra-granular basis and a tri-laminar arrangement of nerve cells, with the granular cells (Golgi Type II and others) on the exterior, whilst the human cerebral cortex is extended by the addition of two other layers outside the granular layer, that is to say, it is a five-layered cortex. The whole construction of the vertebrate nervous system is such as to compel the conclusion that the innumerable short cortical cells of the human cerebral cortex, particularly those within the association areas, are the physical storehouses of memory, and hence of speech, reason, and thought. When, therefore, a medical man writes that "nothing but hopeless confusion can result from the mixture of brain cells and ideas," it is nearer the truth to state that it is exactly this divorce which is responsible for the hopeless confusion, and that the sooner we begin to visualise all mental phenomena in terms of cerebral neurons, the more rapid will be our progress. If the ideas are not in the brain cells, where are they? For what are the numerous brain cells if not for this purpose? Why is it that the human microcephalic idiot is so hopelessly devoid of ideas if it is not because he is so grossly lacking in brain cells? Why is all human progress the result of the work of the multi-neuronic genius, and not of the cerebral ament, who is responsible only for an enormous amount of human suffering, disease, and financial loss? And, lastly, why is it that the late acquisition of speech by a child is always such a significant clinical sign of cerebral amentia?

Speech. The whole phenomena of the acquisition of speech and the allied arts of reading, writing, and so forth, as well as their loss or impairment by disease, are much more nearly related to numbers of neurons, than is generally recognised. Marie urges that in true aphasia intellectual impairment is invariably present. He considers that the notion of intellec-

tual impairment should dominate the doctrine of aphasia. On neurological ground alone it is difficult to see how anyone can fail to be of Marie's opinion.

Man is the only animal gifted with the powers of speech. He is the only animal with large association areas and an adequate supra-granular cortex, and even then his neurons have to be laboriously taught to acquire those properties of speech, reading, and writing, which go to make education possible. If he is under-neuroned from the onset he will find the acquisition of these properties correspondingly difficult, and his intellect or mind will be correspondingly impaired.

It is extremely important to realise that the conception which has so long been held in Medicine, that there is some particular part of the cortex, such as Broca's area, which is the one and only area concerned in speech is absolutely erroneous. At the best the occipital end of the third frontal convolution can be little more than the place of origin of, perhaps, the final common effector pathway for the speech mechanism. It is quite certain, though perhaps difficult of proof, that in the acquisition of speech, many of the neurons of the association areas are vitally concerned, and it is by no means impossible, or even highly improbable, that many of these neurons are the physical storehouses of words and phrases. In accordance with neurological principles these neurons are parts of complicated neuronie arcs, and hence speech is often reflex or automatic in its manifestations.

Examples are common in which the mechanism of language is employed in a purely mechanical manner. Imbeciles can at times learn by rote long paragraphs, of the meaning of which they are quite ignorant. Children learn a large portion of their lessons in the same unintelligent way. Many word complexes are often gone through in a purely mechanical manner, whilst the individual repeating them is thinking of something else. In the majority of persons the word vocabulary, which is in daily use, is very limited, and the phrase vocabulary is both extremely limited, and remarkably stereo-

typed, and is often quite automatically employed. The whole subject of the acquisition of speech, and of its loss by disease, conforms, in a general way with the neurological principles of the neuronics with numerous internuncial neurons.

Whilst it is extremely likely that there are, in the association areas of the human brain, certain regions where there is a convergence of certain neuronics concerned in certain educational functions, such as writing, reading, and so on, it is most improbable that these are absolutely restricted areas, but are much more probably linked together by a complexity of neuronics. On neurological grounds we should not, therefore, ever expect to find the same lesion producing precisely the same results in any two individuals, because there is not only the actual site of the lesion to be considered, but also the depth of the lesion and the question of the involvement of the infra-granular cortex as well as the supra-granular, the numbers of cortical neurons originally possessed by the individual, and the numbers actually destroyed by the lesion. Hitherto clinical medicine seems chiefly to have taken into account only the precise site of the lesion, and seldom the depth, and hence the confusion.

The Human Brain. The purely physical portions of the human neo-pallial cerebral cortex, that is, those concerned with sight, hearing, taste, general sensibility, voluntary motion, etc., remain much as in other mammals, except that they are more richly endowed with supra-granular cortical neurons linked up with each other, and with other portions of the cortex by internuncial neurons, whereas the association areas become greatly extended. Comparative anatomy, evolution, and histology, all compel the conclusion that the association areas of the human brain are the supra-segmental equivalents of the neuropile of the common earthworm. It is, therefore, the neurons of the association areas which form the physical instruments of speech, thought, reason, and the higher mental faculties, and the additions of these faculties is always strictly in accordance with additions of neurons linked together in complex arcs, until, according to Herrick, the sum total is

reached, in the human cerebral cortex, of 9280 million neurons, a number immensely in excess of that possessed by any other animal.

Summary of the General Principles Embodied in This Work. The mode of cortical association between the conducting limbs of neuronics arcs would appear to be a more important subject than has hitherto been supposed, and to play a vital part in all mental phenomena. A close study of the structural details by which this is brought about seems to lead to some quite new conceptions of memory, mind, and speech.

The cerebral cortex is a vast collection of neuronics arcs and synapses, with a complex series of internuncial neurons between the limbs of these arcs. In everything but simplicity, these conform to the type found in all vertebrates.

In the more recently evolved supra-segmental portions of the nervous system the mode of union of conducting limbs of neuronics arcs appears to differ from that of the relatively simple type of the older segmented portions.

These differences in the mode of union appear to be suggestive of the idea that it must be the many short neurons of the supra-segmental portions of the nervous system which have, as their special properties, the storing up, transformation, and dispersal of nerve impulse or nerve energy, and consequently, the granular and associational neurons of the cerebral cortex must be the physical storehouses of memory. This appears to harmonise with known neurological evidence, to throw much light on many mental processes and functional nervous disorder, and to be not inconsistent with physiological opinion as to the functions of the synapses.

The association areas of the human brain are the fields for all the higher mental functions, such as thought, memory, reason, and speech. The capabilities of the human individual in these directions will differ according to the number and mode of connection of fully developed functioning neurons within these areas. "Special talents are due to differences in organisation of special parts of the cortex." (Howell.) These areas, particularly the pre-frontal, are under-developed in low

grade aments (idiots and imbeciles) and to a lesser extent in high-grade aments. (Bolton.) The importance of all this is that we are now beginning to know, and to be able to prove, that there are a number of under-developed human individuals who do not possess a normal number of fully developed cortical neurons, and Bolton's work, as well as that of others, affords ocular and indisputable proof of this. Yet we go on expecting these unfortunate people to react to their environment in a normal manner, and delude ourselves with the idea that Psycho-analysis can replace nature. Just as "bricks cannot be made without straw," neither can a brain deficient in cortical neurons give a normal reaction to the environment, nor can suggestion take the place of such neurons.

From the neuronie standpoint all human individuals may be divided into three great groups. The *cerebral aments* who swell the ranks of our prisons, gaols, reformatories, and asylums, though it must not be supposed that all such inmates are aments. *Normal neuronie* individuals who constitute the vast majority, and the *multi-neuronie geniuses* with more than their fair share of neurons. As a matter of fact there are far more cerebral aments outside these institutions than in them, and many of them find their way into our consulting rooms, where they remain largely unrecognised, or drift into the hands of cranks and quacks who are not improbably as under-neuronied as their victims. As will be shown later the diagnosis of amentia can not only be made during life and with considerable accuracy, but some indication of the state of development of the cortical layers can, in many cases, be obtained in addition.

Man is the only animal with highly developed association cortical areas. He is the only animal to speak, think, and reason, and he does so because he has not fewer than three times as many cortical neurons as any other animal, hence, a study of brain structure is an essential first step in the study of mind and its aberrations.

CHAPTER II

THE GENERAL STRUCTURE OF THE NERVOUS SYSTEM

Structural Units. The nervous system of man consists, as does that of all animals, of structural units or cells, termed *neurons*, held together and supported by a special sustentacular or connective tissue, *neuroglia*, assisted by ingrowths of connective tissue from the investing membrane, the pia mater, together with *ependyma cells*, which are epithelial cells, usually ciliated, lining the cavities of the brain and spinal cord. There are thus three varieties of cells—neurons, with their processes, neuroglial cells, and ependymal cells. Of these the first are of supreme importance in the study of the nervous system, and it is essential that the whole of the nervous system should be visualised and studied—from the standpoints of function and loss of function—in terms of neurons, of which there are many millions in the human body.

The Neuron Doctrine. The neuron doctrine, based on the embryological researches of His, and the histological investigations of Cajal, was first put forward by Waldeyer in 1891, who was also the first to apply the term *neuron* to the nerve cell and its processes. This doctrine enunciates the facts that the neurôn is the genetic unit of the nervous system, each one being derived from a single embryonic cell, the neuroblast; that every neuron is anatomically quite distinct and separate from every other neuron, but establishes physiological contact with its fellows at the neurosynapse; that neurons become linked together into chains and arcs, and that until they do so the neuron cannot function; that the neuron is a trophic unit, and is the sole element along which nerve impulse is conducted.

The Neuron as the Unit of Nerve Structure. The neuron

is a highly modified, specialised, and irritable cell which forms the morphological unit of the nervous system. Neurons cannot be seen by the naked eye, but when a sufficiency of them,

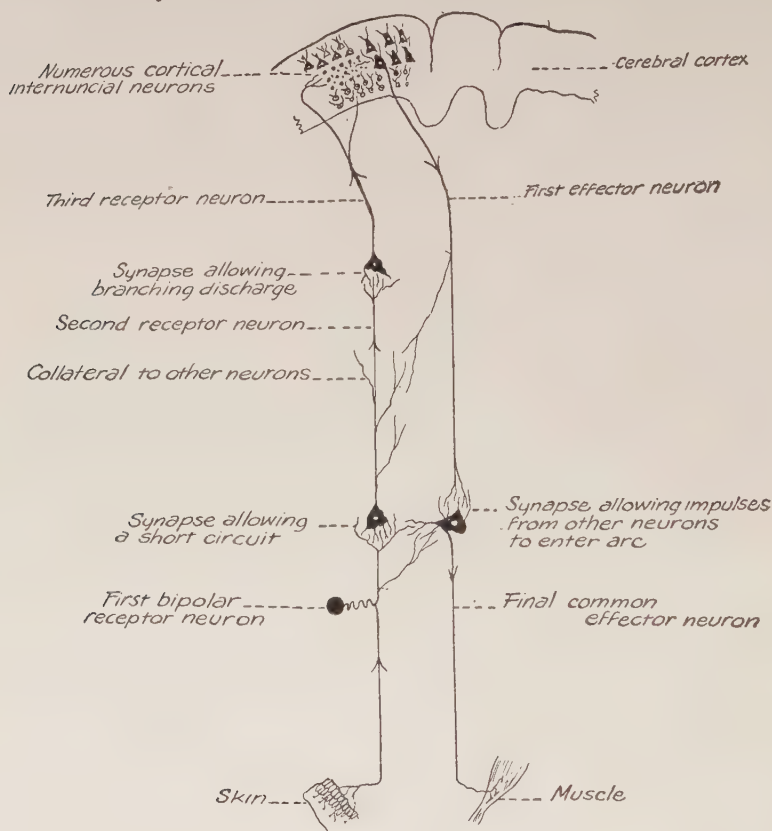


FIG. 7.—The neuron doctrine as illustrated by a cutaneous-muscular reflex. See pages 2, 5, 8, 21, 35, 37.

running to thousands or millions, are massed together, united into chains and arcs, there is found a visible structure like the brain or spinal cord.

When fully developed, each neuron is composed of a nucleated cell-body and one or more processes. If only one process be present it most usually functions as an axon, and becomes the axis cylinder of a medullated nerve fibre, or forms the bulk of a non-medullated fibre. If two processes be present,

both may function as axons, as with the neurons of the dorsal root ganglia of the spinal nerves. Much more frequently, however, there is one axon and one or more dendrons, which, with the cell-body, make up the neuron. The dendron usually ramifies widely in close vicinity to the cell-body. The physiological path of conduction is usually through the dendrons towards the cell-body and axon, and away from the dendrons and cell-body by way of the axon and its collateral branches. This constitutes the so-called *law of conduction*, or the *law of forward direction*, within the neuron. To this law the neurons of the dorsal root ganglia of the spinal nerves appear to be an exception, as the peripheral process, which seems to act as an axon, habitually conducts impulses from the periphery towards the cell-body.

As the length of the axon differs very considerably, neurons may be divided into long and short-axoned. The former effects communications between distant parts of the nervous system, or between the periphery of the body and the nervous system. The short-axoned neuron usually effects communications between adjoining neurons, which are thus associated together, and linked into a physiological whole. Between these two extremes as regards length of axon there are many intermediate forms, and as a general rule, the longer the axon the larger the cell-body.

Structure of the Neuron. The properties of irritability, conduction, and correlation are the most distinctive features of the nervous system, hence neurons or nerve cells are *constantly* receiving stimuli, and generating and storing up nerve impulses. Whether the impulses generated by the neuron are chemical, electrical, or combinations of both, is not definitely determined. Neurons have, in addition, the property of conducting nerve impulse, and of transmitting the impulses which they generate, after stimulation, to other neurons, some of which appear to act as storehouses for the impulses so transmitted to them. Although the neuron is, as has been seen, a single and independent anatomical unit, it is impossible for it to function alone. Every neuron must be linked up

with others in conducting chains and arcs, and thus the impulse generated by any one neuron of necessity affects other neurons. The remarkable properties of neurons thus require a highly specialised structure.

Like all other bodily cells, a neuron consists of a nucleus surrounded by cytoplasm, and although these generally resemble those of bodily cells, each presents, in the neuron, certain more or less characteristic features confined to the neuron.

The *nucleus* of the *cell-body* of the neuron is large and spherical, and is usually situated at, or near, the centre. It differs only slightly from the nucleus of the ordinary cell, but contains little chromatin, and hence stains lightly with the basic dyes. It represents here, as in other cells, the vital centre of the metabolic processes.

The *cytoplasm*, enclosed in the cell membrane, and surrounding the nucleus, is made up of a fibrillar network called the *spongoplasm* or *achromatic net*, and contains small angu-



FIG. 8.—Structure of the neuron. Two cells from ventral horn of human spinal cord. (Nissl's method.) The chromatic substance is collected into small masses, which give a speckled appearance to the cytoplasm. Each cell, besides the nucleus and nucleolus, contains a distinct mass of stainable granules. (From: Luciani, "Human Physiology.")

lar patches of a proteid material, *neuro-chromatin*, which is apparently a product of the nucleus. This neuro-chromatin tends to become grouped into clumps, which stain deeply with basic aniline dyes, such as methylene blue, and form the *Nissl bodies or tigroid masses*. The arrangement and disposition of these Nissl bodies within the cytoplasm of the cell-body of the neuron vary in different cells, and it is possible to tell, by this criterion alone, to what functional group the neuron belongs. The Nissl bodies are, for example, larger in effector cells than in receptor. The exact significance of these Nissl bodies is still open to question, as is also their presence in the living neuron itself, but they would appear to be concerned in some way with the functional activity of the nerve cell, and to vary with its condition, for the histological appearances of stained specimens of fatigued nerve cells differ from those of normal nerve cells. In the former the Nissl granules become dissolved and diffused throughout the cell, or may decrease or even disappear altogether, whilst the cell body correspondingly diminishes in size and the nucleus in bulk. To these important changes in the nerve cell, the results of fatigue, is applied the term *chromatolysis*. A chromatolysed neuron will not function as efficiently as one in which the processes of fatigue have been repaired by rest or treatment, and if the chromatolytic process be too long continued the neuron will become destroyed, and hence there must be some forms of prolonged disease which cause a chromatolytic death of neurons and so impair future mental reactions.

Within the cytoplasm are also found some extremely fine filamentous threads, termed *neurofibrils*. These pass through the cytoplasm in every direction and are believed to extend into the processes as well, that is, into both dendrons and axon. They are possibly the elements concerned in the actual conduction of the nerve impulse, and, according to Jiegs are continued, in the rabbit, cat, and guinea pig, from one neuron to another through the dendrons.

Concerning the presence of a *centrosome* within the cell-

body of the neuron there is a conflict of opinion. It is, however, most probable that the centrosome is not present in the neurons of most vertebrates, because the centrosome appears to be the initiator of cell division, and neurons have become so highly specialised for purposes of conduction and other functions, as to have lost this power of reproducing themselves, and it is a matter of much significance that nerve cell tumours are unknown. Clinically this matter is of considerable importance because, if the neuron is incapable of reproducing itself, it follows that once a series of neurons is destroyed, from any cause whatsoever, there must be a corresponding loss of function, and this is, perhaps, particularly applicable to the brain, where every serious cause of neuronie destruction must be followed by a corresponding impairment of intellectual function.

In addition to the neuro-chromatin there may be, in the cell-bodies of some neurons, *other pigments*, as for example, in the deeply pigmented cells of the substantia nigra of the midbrain. As a general rule such deeply pigmented cells are large and are apparently of the effector order.

The *cell-body* or *cyton* of the neuron is thus a highly specialised structure, and assumes many different forms and sizes. It may be pyramidal, pyriform, globular, stellate, or fusiform in outline, and differs from almost all other cells in the body in the fact that it possesses processes of varying length and ramification and termed dendrons and axons.

The *dendrons*, *dendrites*, or *protoplasmic processes* usually come off the cell-body in the form of a stout process or processes, which undergo repeated division in the immediate neighbourhood of the cell-body itself. They contain Nissl bodies, and are usually regarded as receiving organs, that is, they receive a stimulus or impulse from some other source or neuron, and convey it towards the cell-body of their own neuron. The rods and cones of the retina are, for example, modified dendrons which act as receptor organs for light stimuli. The size, length, and mode of branching of the dendrons are chiefly determined by their relations to other

neurons from which they receive their nerve impulses. As they spread widely throughout the surrounding tissues they not only give the cell-body a large surface for the rapid absorption of food materials from the surrounding lymph, but they also bring the neuron into relationship with many other neurons.

The *axon* of the neuron is a slender, smooth process of uniform thickness, and is, therefore much less conspicuous than the dendron. Each neuron usually has but one axon, and this differs from the dendron in its clearer appearance, due to the absence of Nissl bodies; in its generally smaller and more uniform size, and lastly, in its manner of arborescence. The axon does not, as a rule, arborise near the cell-body, as does the dendron, but gives off fine lateral branches, termed *collaterals*, which bring it into contact with other neurons, and these, like the parent process itself, are usually medullated.

Axons differ very considerably in their length, so much so, that neurons may be divided, as has been seen, into long-axoned and short-axoned. They thus vary from 1 mm. or less, where the whole neuron is confined to the grey matter, to more than 1 metre, as in those which connect the foot to the spinal cord. As a general rule the longer the axon the larger the cell-body.

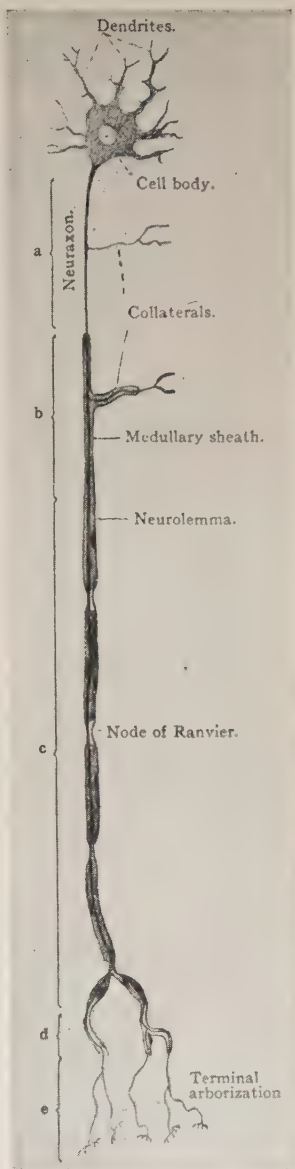


FIG. 9.—Diagram of a neuron. (From: Lewis & Stohr, "Textbook of Histology.")

As the axon is the conducting path of the nerve impulse generated by the cell-body, it is often necessary, just as it would be with an electric wire, for the axon to be insulated. In most neurons of the central nervous system, it is, therefore, found that the axon, soon after leaving the cell-body, becomes surrounded by a *medullary sheath*, thus giving rise to a medullated nerve fibre. Notwithstanding that the function of the medullary sheath is usually regarded as insulating only, to prevent the overflow and loss of the nerve impulse conducted by the axon, there is some evidence to show that the medullary sheath also plays an important part in the chemical processes involved in the act of nerve conduction. As the axon approaches its destination it frequently loses its medullary sheath and terminates in a series of naked and branched axon cylinders.

The naked axis cylinder process appears to be an earlier evolutionary form of conducting apparatus than the medullated axon and to subserve more primitive functions. The autonomic nervous system, which is certainly a more primitive type of nervous system than the central nervous system, contains more non-medullated axons than does the latter, and it is extremely important to remember that if an axon should myelinate, and fails to do so, the neuron will be unable to function. The completion of the process of myelination is the sign of maturity of the neuron.

With the exceptions of some of the non-medullated axons of the autonomic nervous system, practically the whole of the white substance of the brain, spinal cord, and peripheral nerves is composed of the medullated axons of neurons. There are thus two great varieties of axons in the human body, those which are insulated, termed *medullated axons*, and those which have no such insulating sheaths, but pass to their destination, as naked axis cylinder processes, and hence termed *non-medullated axons*.

Medullated axons are composed of the central conducting process of the neuron itself, the axis cylinder or "live wire." This is surrounded by a relatively thick sheath, the *myelin*

or *medullary sheath*, and a nucleated membranous *neurilemma sheath*. The former is highly refractive and this gives to such axons, when seen in cross section, a characteristic whitish appearance. At certain places along the course of the axon it is interrupted at regular intervals by constrictions in its substance, termed *nodes of Ranvier*, and at which the more external neurilemma dips in towards the axis cylinder. Each section of the axon between these nodes of Ranvier forms an internodal segment and is provided with its own nucleus, which lies just internal to the neurilemma sheath, and is the product of a single sheath cell of ectodermal origin. It is to be noted that those axons which are found within the brain and spinal cord differ in structure from those described above within the peripheral nerves, inasmuch as there is no segmentation in the medullary sheath, nor are the neurilemma nuclei present—facts which clearly have much significance on axon regeneration. There are, therefore, two types of medullated axons. Those which make up the peripheral nerves and possess the features described above, and those which make up the bulk of the white matter of the spinal cord and brain and lack the neurilemma and nuclei.

Non-medullated axons appear to be an earlier evolutionary type of conducting axon than the medullated, and consequently such axons are chiefly found in the more primitive portions of the segmented nervous system, and also appear to subserve more primitive functions. These, too, are of two kinds, the primitive naked unmyelinated axon with a fine neurilemma and a nucleus or nuclei, which is especially abundant in the autonomic nervous system; and the entirely naked axon, which chiefly occurs in the grey matter of the brain and spinal cord as the process of a fine small internuncial cell. All axons, whether of the medullated or non-medullated varieties, tend, of course, to be devoid of a sheath at their commencements and terminations.

Types of Neurons. Neurons present, as has been seen, so many differences in the size and form of their cell-bodies and of their processes, as to make any classification, from either a

structural or a functional standpoint, an almost impossible, or at least, useless task. There are, however, at least three distinct types of neurons, whose form and structure throw light on their functional significance. These are the bipolar neurons, and the Golgi neurons, Types I and II, of multipolar order.

The typical *bipolar neuron* is generally receptor in function, and, although it is, developmentally, really a bipolar neuron, it appears in the adult as a unipolar neuron, because the two processes, central and peripheral, fuse together, and so arise from the cell-body as a single process. At some little distance from the cell-body, this process divides into a central and a peripheral process. The former passes into the central nervous system, and the latter to the periphery, which it reaches in some one or other of the peripheral nerves.

Bipolar neurons make up the bulk of the dorsal spinal nerve roots. The cell station is in the dorsal nerve root ganglia. The central process passes inwards to the spinal cord, and the peripheral process runs peripherally in the spinal nerve itself. The mode of conduction is from the seat of stimulation along the peripheral process to the cell-body, and thence

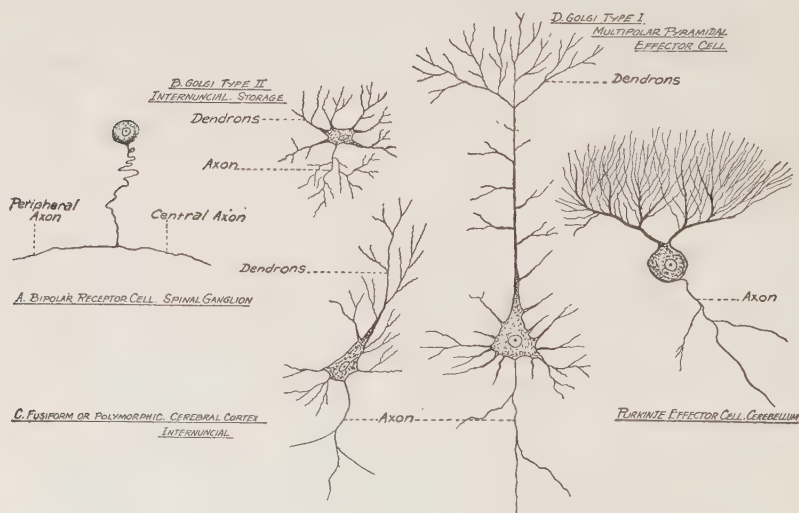


FIG. 10.—Types of neurons. See pages 29, 280, 358, 369.

along the central process to the spinal cord, so that it is usual to term both processes—central and peripheral—axons, because both processes possess all the morphological characteristics of axons. Whilst it is undoubtedly true that the mammalian spinal ganglion is composed largely of these characteristic receptor bipolar neurons, other varieties are also found therein, and Dogiel has recognised no fewer than eleven different varieties of neurons with their cell stations in the dorsal root ganglia, and there are both myelinated and non-myelinated axons in their vicinity. These facts may possibly have some importance in connection with the mode of conduction of protective pain stimuli from the skin. Bipolar receptor neurons are, of course, found in many other parts of the body besides the spinal nerve ganglia, but the important point is that most bipolar neurons are receptor in kind and conduct centrally.

Of the multipolar varieties of neurons, *Golgi Type I* possesses both dendrons and axon, and is characterised by the fact that the medullated axon usually leaves the central grey matter and becomes a nerve fibre, or a medullated axon of the white matter. Within the substance of the central nervous system this axon may also give off numerous collaterals which establish physiological contact with other neurons. This variety of neuron is frequently effector in type, and conveys nerve impulses peripherally. To this group belong many of the pyramidal cells of the cerebral cortex, the ventral horn cells of the spinal cord, and the specially modified effector Purkinje cells of the cerebellar cortex.

It is of importance to note that most of the long conducting neurons of the central nervous system belong to one or other of these two types—the receptor sides of the neuronics are mostly composed of bipolar neurons, and the effector sides of the arcs of multipolar Golgi Type I neurons.

The *Golgi Type II neuron* is also a multipolar one, but is quite different in structure and function from the others. It is characterised by the fact that its axon does not form a nerve fibre, but splits up into a large number of terminal ramifica-

tions which are strictly confined to the grey matter in which they are found. These neurons would, on the general principles of the neuron doctrine, appear to be interposed between the receptor and effector limbs of the neuronic arcs, particularly so in the supra-segmental portions of the neuraxis, where they are very numerous. So situated, these neurons are termed *intermediary* or *internuncial neurons*, and they appear to possess the properties of being able to store up nerve energy transmitted to them by other neurons, and of liberating it at a later period under suitable stimulus. This type of cell is, indeed, so numerous in the cerebellar and cerebral cortices that it is impossible to account for their presence in any other way, and they thus appear to play a very important part in the phenomena of cerebellar energy and of mind.

The Neuroglial and Ependymal Elements of the Nervous System. As these elements play no part in nerve conduction or generation, but are supporting or lining only, they are of little importance. As to *neuroglia* there is, however, one important observation to be made, and that is, that its amount in the cerebrum appears to vary considerably in different individuals. If the spongioblasts develop at the expense of the neuroblasts, or in excess of the neuroblasts, a large heavy brain and a large head, with a normal or even a diminished number of neurons may result, or conversely, if the neuroglia be considerably less in amount, there may result the small-headed type of intelligence, which is much rarer than the big-headed type of genius. Of these processes there are many abnormal examples, most of them being developmental in origin. There must thus clearly be distinguished the multi-neuronic large brain of high intelligence or genius, and the multi-neuroglial heavy brain and big head of ordinary or deficient intelligence.

CHAPTER III

THE FUNCTIONAL WORKING OF NEURONS

Nerve Energy. That the nervous system generates energy is undoubted, and this energy appears to be developed, as a result of stimulation, within the cell-body and the dendrons, whilst the axon acts as the conductor. If a human individual possess a diminished number of cortical neurons, from pre-natal errors of development, or from post-natal causes, he will be incapable of the same "intelligent" action as the more fortunately endowed individual. Just as with electric action, an insufficient number of batteries, an imperfectly connected series of batteries, or an improper insulation, give indifferent results, so also is it with the human nervous system. An insufficient number of cell-bodies, an imperfectly connected series of neurons, or insufficient medullation of axons, especially within the white matter of the brain and spinal cord, give marked differences in the display of intelligent action.

It is generally believed and assumed that nerve energy results from chemical or metabolic changes in the cell-body of the neuron and dendron, and that excessive activity from overstimulation results in the exhibition, within the nerve cells, of the phenomena of fatigue (chromatolysis). Generally speaking, the cells of all tissues exhibit a balance between the processes of consumption of material associated with activity, and the processes of repair. If a proper interval of rest be allowed, the tissue will function without exhibiting fatigue. If, however, the stimulation be too strong, or repeated at too brief an interval, then the processes of repair do not keep pace with those of consumption, and the phenomena of fatigue are produced. If these conditions are extreme, the chromatin material may become entirely removed

from the cell-body of the neuron, a condition which leads to a functionally exhausted cell. Amongst some of the many causes of chromatolysis in nerve cells are excessive stimulation, many drugs, almost all poisons, such as alcohol, the toxins of disease, as, for example, syphilis, and an insufficiency of oxygen. If the cause of the chromatolysis be not removed in time the neuron will be destroyed, and there will be a corresponding diminution of nerve action.

As the intellectual activities of the individual are largely dependent on a sufficiency of normally developed and properly connected neurons, and as the whole of the neurons which the adult is to possess are present at birth, either in the form of embryonic neuroblasts or matured neurons, and as there is no regeneration after destruction or death of any fully developed neuron, it follows that any pathological process which tends to interfere with the post-natal conversion of neuroblasts into neurons, or destroys such neurons after complete development, has an extremely serious result, not only on the individual, but also on those with whom he comes in contact, because his reactions to the social environment will naturally differ from those regarded as normal by normal people.

Conduction of the Energy Generated by the Cell-Bodies of Neurons. Energy generated by any neuron will infect the whole of that neuron, and will be conducted from the cell-body, or generating station, by the axon. According to the direction of the conduction all axons convey nerve impulse either centrally or peripherally, that is, the neuron is either receptor or effector in type. The bulk of the white matter of the spinal cord is made up of long receptor axons conducting nerve impulses centrally, and of effector axons conducting such impulses peripherally. These types of neurons have long been known in medicine, and lesions thereof produce well-defined and easily recognisable conditions, but it is now known that there is a third type of neuron which is entirely confined to the grey matter in which it is found, and is neither receptor nor effector in function. Some of the neurons of this

class are of the Golgi Type II variety, and are present in very large numbers in the supra-segmental portions of the neuraxis, particularly so in the grey cortices of the cerebellum and cerebrum. Such neurons apparently serve the purposes of storing up nerve energy and are usually found interposed between the receptor and effector neurons. They are hence termed *internuncial* or *intermediary neurons* and play an important part in the phenomena of mind. It consequently follows that neurons are unable to function unless they are linked together into chains and arcs.

Inter-Relation of Neurons. In the invertebrates the mode of conduction of nerve energy is relatively simple. A single cell may receive the stimulus and transmit it at once to the effector cell. In all vertebrates the process is much more complicated. In them the transmission of nerve impulse necessitates at least one receptor neuron and one effector neuron, and in most cases considerably more. As each neuron is an absolutely independent embryological and anatomical unit, it follows that between any two neurons there is an anatomical break in the structural continuity. At this structural break or *synapse*, as it is termed, the neurons involved are simply in contact and the nervous impulse passes from one to the other across this very short gap in the conducting substance. More properly speaking, the nerve impulse does not pass from one neuron to another, but affects the second neuron in the chain, causing it to discharge a fresh impulse, and this the first one has to do across the synapse. In the functional workings of the nervous system, as a whole, the presence of these innumerable synapses, with their manifold possibilities of irradiating discharges of nerve impulses, and their potentialities of admitting nerve impulses from other and improper sources of nerve energy, is of the utmost physiological and clinical importance.

Whilst it appears to be well established that the axon of any neuron can conduct nerve impulse equally well in either direction, it is equally well established that such impulses can only cross the synapse in the one direction, that is, from

the axon of one neuron, across the synapse, to the dendron or cell-body of the next neuron. This *dynamic polarity* is, therefore, clearly due to some inherent characteristic of the synapse itself, and not to anything within the neuron. If, for example, an effector axon bifurcates into two branches, each of which passes to a separate muscle, stimulation of the one terminal will cause an impulse to travel up the stimulated axon to the point of bifurcation and down the other terminal branch to the other muscle, the phenomenon being known as the *axon reflex*.

In all vertebrates neurons are, therefore, linked up into chains and arcs, and each neuron is separated from the others in the physiological chain, by synapses, across which the nerve impulse must pass, and such nerve impulses only cross the synapse in the one direction, from axon to dendron or cell-body.

Neuron Chains and Arcs. The neuron is an anatomically independent structural unit, which can only function when it is linked up with other neurons in the forms of neuron chains and arcs, and it is one of the first tasks of Neurology to ascertain how the neurons are so linked and along what paths of neurons do nerve impulses normally pass. Most of the phenomena of the nervous system are concerned with the linking up of neurons into arcs, many of which work automatically and so constitute *reflex arcs*. The various structural elements which go to the making up of a neuron arc have been set forth in chapter I (see page 3), as have also the several types of neuron arcs known to exist in the vertebrate neuraxis. Taking the well-known phenomenon of the knee-jerk as an example, what happens here is that the blow on the infrapatellar region stimulates a receptor neuron to activity, causing it to generate nerve impulse. This impulse traverses a bipolar receptor neuron which sends its central process into the spinal cord, where it effects synaptic contact with the effector neuron of the arc concerned. This effector neuron, which is of the multipolar Golgi Type I variety is thereby stimulated to discharge its nerve impulse which is

transmitted peripherally to the muscle concerned, and so the muscle contracts, and the jerk is produced. The impulse generated in the receptor neuron, as the result of the stimulus, must cross the synapse between the receptor and effector neurons concerned, before the latter can be induced to respond. Such a type of neuronic arc with but two neurons, the one receptor and the other effector, is rare in the human body, and is an example of Cajal's *epoch of the reflex arc*, though, according to Jolly, the human patellar reflex is such an example. Much more frequently the arc is more complicated and there are interposed between the receptor and effector neurons one or more shorter neurons, which are internuncial in nature, and may be either associational, commissural, or storing in function. Such arcs, where other neuronic elements are interposed between the receptor and effector neurons, constitute examples of Cajal's *intersegmental reflex neuron*, and the possibilities of branching discharge at the synapses are more numerous, because there are obviously more such junctions than in the simpler neuronic arc with but two neurons and one synapse. It is to the ever-increasing complexity of these interposed neurons between the longer conducting limbs of the arcs that the nervous system of mammals and man owes its complications and the difficulties of its study.

The Synapse. In the central nervous system the synapses would everywhere appear to form an absolute block to the passage of a nerve impulse backwards, that is, from the cell-body or dendrons into the end ramifications of an axon, hence the law of forward direction referred to. Further, the neuron systems are so complex and so extensively associated at the innumerable synapses that an impulse passing through any one given axon could, theoretically, spread to every other neuron, and such a result is, indeed, actually the case in animals poisoned by strychnine. "That this result does not ensue on localised stimulation in a normal animal is dependent on the varying resistance to the passage of an impulse into the several neurons with which the entrant fibre comes in

relation. A small stimulus will discharge only along the few neurons where the resistance is lowest. Increase of the stimulus, either by increase of its strength or by summation of weak stimuli, will enable the impulse to spread along more neurons, and will therefore elicit a more widespread response. Only when the synaptic blocks are entirely removed by the administration of strychnine, or when the stimuli are abnormally powerful and long continued, will the impulse spread to all regions of the central nervous system, so that response becomes general and inco-ordinate instead of local and adapted to the stimulus." (Starling.)

Herrick regards the following important points about the synapse as well established:

Unimpeded protoplasmic continuity across the synapse has not been proved, and in some cases there is clearly a membranous barrier interposed between the two neurons. But the exact nature of this barrier is unknown and it by no means follows that the synaptic membrane is an inert substance. It may be composed of living substance of a different nature from that of the other protoplasm of the neurons.

The transmission of the nervous impulse across the synapse involves a delay greater than that found in the nerve fibre or the cell-body. This suggests that there is some sort of an obstruction here which does not occur elsewhere in the reflex arc.

The synapse is more susceptible to certain toxic substances, such as nicotine, than is any other part of the reflex arc.

Though a nerve fibre seems to be capable of transmitting an impulse in either direction, the nervous impulse can pass the synapse in only one direction, namely, the direction of normal discharge from the axon of one neuron to the dendron of another. The synapse, therefore, acts as a sort of valve, to use a crude analogy, and appears to be one of the factors, though not necessarily the only one, in establishing the polarity of the neuron, that is, which is responsible for the law of forward direction.

Observations upon injured neurons show that the degen-

erations caused by the severance of their fibrous processes (whether these be manifested as degeneration of the fibres or as chromatolysis), or by the destruction of the cell-bodies from which the fibres arise cannot cross the barriers interposed by the synapses.

These opinions, the one physiological, the other neurological, show the very great importance of the synapses interposed between the neurons, in the functional working of the nervous system. In the first place these synapses offer to incoming receptor impulses a choice of subsequent routes. For example, a receptor impulse entering the spinal cord along a bipolar receptor neuron may, on reaching the spinal cord synapse, pursue a variety of subsequent neuronic paths. It may flow at once into an effector neuron and thus confine itself to a simple two-neuron reflex arc; or it may affect an interposed association neuron of the same or other spinal cord levels, and thus the route will be over a three-neuron arc; or it may pass upwards to higher levels of the neuraxis and may thus traverse a number of neurons; or it may eventually reach the brain, where it will involve an enormous number of cortical neurons, and may not give rise to any immediate effector response. In this case the nerve impulses have clearly become arrested, as it were, in the mesh-like neuronic net of the cortical cells, and are there stored up for future use.

What exactly determines the route or routes pursued by nerve impulses is more difficult to determine, but is clearly influenced by the synapses. Conduction across a synapse may vary from moment to moment, according to the actual physiological condition of the neurons themselves. A neuron in a condition of temporary chromatolysis will clearly alter the nature of the conduction across the synapse, and if such neurons be destroyed as a result of prolonged chromatolysis, the whole nature of the conduction, as well as the synapses concerned, will be seriously altered. It consequently follows that, even in health, the course pursued by nerve impulse is not always along the same neuronic routes, and in disease the routes become still more altered and modified. The physi-

ological tendency, however, is that once a nerve impulse has established a particular neuronc route for itself it continues to follow that route, and many of these routes are laid down before birth and follow an hereditary pattern. In the newborn child, for example, the neuronc arcs involved in breathing and swallowing are perfect, and are always the same and have been handed down through a long ancestry. With cortical neurons and their connections it is quite different, hence the impossibility of forecasting the particular mental and individual reactions which will follow the stimuli. Post-natal development is largely concerned with the perfecting of the neuronc routes through the cerebral cortex, and if these be imperfect from the outset some form of mental impairment must accrue.

Importance in Health and Disease of the Neuronc Arc.

It is impossible to overestimate the importance of the neuronc arc in both health and disease. Every phenomenon of life is entirely dependent on the incoming of stimuli from many sources transmitted centrally over the receptor limbs of neuronc arcs. If these stimuli were to cease entirely death would result. The effector responses enable the animal to change its environment in response to the receptor stimuli.

Disease is also largely a matter of disturbances of normal neuronc arcs, and there is no disease, whether functional or organic, which does not, in some way, disturb the normal conduction of nerve impulses over these arcs. In some instances current medical knowledge can place accurately the alteration, induced by the disease, as being on the receptor side of the mechanism; in others, it is equally certain that it is the effector side which is the seat of the alteration. In the vast proportion of cases, especially in visceral and functional disturbances, medical knowledge is insufficient to locate the arcs concerned, and so the importance of the disturbances induced in the neuronc arcs by disease is lost sight of. It is, however, true, and when the neuronc paths, even as known today, are as well known by the clinician, the diagnosis and treatment of disease will be bettered.

As examples of the foregoing general statements, locomotor ataxia is a disease in which the *receptor* limbs of proprioceptive arcs are cut off, and thus the impulses normally conveyed over these neurons—the gracile and cuneate tracts—no longer reach the cerebellum. The cerebellum is thus no longer informed of the position and state of the muscles, tendons, and joints, and the staggering gait results. Infantile paralysis, on the other hand, is a disease affecting the *effector* side of a neuron arc. Many of the aphasias, mental aberrations, and the like, are caused by a local destruction of the cortical *internuncial* neurons. In the case of viscera the exact course pursued by the receptor and effector neurons of the autonomic nervous system is not, at present, as well known as are the longer conduction paths of the spinal cord, and hence it is not, in many cases, easy or possible to recognise the side of the arc which is disturbed by the disease. Pyloric stenosis is a disease in which the important physiological balance between the receptor and dual effector regulating mechanism is disturbed. There can be no question that when the importance of referring all nervous and clinical phenomena to the neuron arc is more generally recognised, there will be a corresponding improvement in therapy.

It has already been pointed out that the synapse offers to incoming receptor stimuli a choice of subsequent routes, and that the constant transmission of impulses tends to “track” the neuron route followed. It is almost equally important to recognise that, under pathological conditions, the synapse offers the possibility of impulses being admitted from abnormal sources, that is, nerve impulses may become side-tracked, as it were, on to incorrect paths. There is little doubt that some of the mental phenomena presented by the insane, with their constant obsessions, fixed ideas, and so forth, is something of this nature, though it is naturally impossible to indicate which of the millions of possible cortical neuron paths are being followed either in the mentally normal or the mentally aberrant. The possibility here indicated should not, however, be lost sight of in the study of nervous and mental disease.

As an instance of an *aberrant stimulus* traversing a receptor neuron with the production of a symptom, the familiar instance of toothache may suffice. Every tooth is furnished with its own receptor neurons and conveys impulses centrally. When the tooth becomes carious the nerve is exposed and becomes liable to stimulation from aberrant sources to which it is not normally intended to react. Amongst these are the chemical constituents of the saliva, or the mechanical irritation of food particles. The result is the dental receptor neurons from the tooth concerned are wrongly stimulated and pain results. With the injection locally of cocaine the dentist paralyses these receptor neurons and is thus enabled to extract the tooth without the perception, by the patient, of any pain. If the study of disturbance of function and disease generally be interpreted in terms of the neuronics the clinician will find that the case very frequently becomes more interesting, more instructive, and more amenable to treatment, because if the cause of the disturbance can be diagnosed and removed, a cure must be effected.

CHAPTER IV

THE ANATOMY OF THE NEURONS

Neurons in Mass. Neurons are microscopic structures which cannot be seen with the naked eye. When massed together, however, in series of chains and arcs, and in thousands of millions, they form, together with the neuroglia in which they are embedded, the bulk of the visible brain, spinal cord, and peripheral nerves, that is, of the central or somatic nervous system, as well as of the autonomic or visceral nervous system. It thus follows that, from the purely anatomical standpoint, the nervous system of man is usually regarded as consisting of two main parts:

The central, cerebro-spinal, or somatic nervous system.

The autonomic (sympathetic) or visceral nervous system.

Both of these parts are built up of neurons linked together in series of chains and arcs, connected with each other.

Naked Eye Differences Between Cell-Bodies and Axons.

On section of either brain or spinal cord a differentiation into *grey* and *white matter* is readily seen, even with the naked eye. The cell-bodies of the neurons are strictly confined to the *grey matter* of brain, spinal cord, and the various ganglia of the central and autonomic nervous systems. The *white matter* is exclusively composed of the medullated axons of the neurons, and contains no nerve cells whatsoever. Grey matter is, however, composed of other structures besides the cell-bodies of neurons. It is largely an intermingling of dendrons, cell-bodies, and axons. In the case of both grey and white matter, the nerve units are embedded in neuroglia.

Special Methods for the Study of Neurons. As neurons cannot be seen with the naked eye, many ingenious and special methods have had to be devised for their study, and for the

and thus to trace the course normally followed by the axons concerned. When the information so obtained is combined with the symptoms of the disease during life, it throws light on both the course and functions of the axons concerned.

The Central, Cerebro-Spinal, or Somatic Nervous System. The central or somatic nervous system comprises the spinal cord, brain stem, cerebellum, brain, and the cerebral and spinal nerves attached thereto, together with certain ganglia found upon the roots of some of these nerves. These several parts will be fully described in due course.

The Autonomic (Sympathetic) or Visceral Nervous System. The autonomic (sympathetic) visceral, or involuntary nervous system comprises the whole of the visceral system of nerves. It is in no sense an anatomically independent nervous system, but is an offshoot from the central nervous system, by which it is to a large extent controlled, though it seems probable that many of the simpler

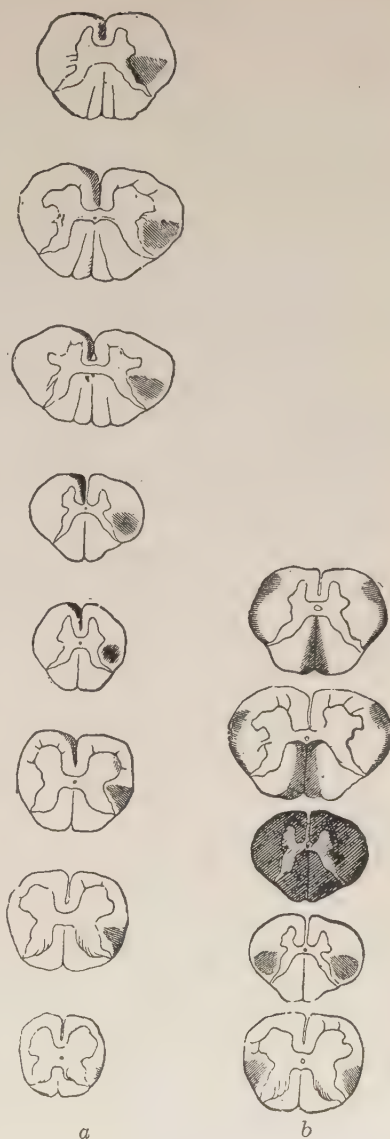


FIG. 12.—*a*, Secondary descending degeneration due to a lesion in left cerebral hemisphere. (After Erb.) *b*, Secondary ascending and descending degenerations due to lesions of upper thoracic cord. (After Strümpbell.) (From: Luciani, "Human Physiology.")

reflexes of the splanchnic or visceral organs are purely autonomic functions, which are mediated separately and without rising to the level of consciousness.

Anatomical Subdivision of the Autonomic Nervous System. The autonomic nervous system is divided into a central and peripheral part. The *central part* is represented by groups of nerve cells found chiefly in the midbrain, medulla oblongata, and in those regions of the spinal cord other than the cervical and lumbar enlargements, which are primarily occupied by the effector and other cell stations of the limb plexuses. The *peripheral part* is represented by the axons of the cells of the central part, which pass out of the central nervous system, to end around the ganglia of the autonomic nervous system, whence a fresh series of neurons convey the impulses to their ultimate destinations. The former are, therefore, termed *pre-ganglionic*, because they lie on the central side of the ganglia concerned, and the latter, *post-ganglionic*. The autonomic nervous system is, therefore, distinguished by its connections with neurons *outside* the central nervous system, and by the formation of peripheral plexuses or networks at its places of distribution. It subserves those functions of organic life which, though not under the control of the will, are essential for the maintenance of vital reactions.

The *peripheral portion* of the autonomic or visceral nervous system consists, anatomically, of two main parts, only one of which is visible to the naked eye. These are as follows:

1. The parasympathetic system, or the system of the extended vagus. Largely invisible to the naked eye.

Midbrain or tectal autonomies.	}	Cranial outflow.
Bulbar autonomies.		
Sacral autonomies.		Sacral outflow.
2. The vertebral sympathetic system. Visible to the naked eye.

Thoracic autonomies.	Thoracico-lumbar outflow.
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The Parasympathetic System or the System of the Extended Vagus. The parasympathetic system does not form a visible anatomical chain like the vertebral sympathetic,

but consists of microscopic nerve fibres (axons) which run to their destinations within the sheaths of some of the cerebral and spinal nerves, to end in ganglia situated more peripherally. It is further to be noted that parasympathetic neurons of both the receptor and effector orders may course in the same nerve sheath, so that if the vagus nerve be divided, the passage of nerve impulses in either direction may be arrested, hence the experimental difficulty of obtaining accurate results as to the course and functions of autonomic neurons of this order.

The *cranial outflow* of the *parasympathetic system* comprises the midbrain or tectal autonomies, and the bulbar autonomies, arising from the midbrain and medulla oblongata respectively. The axons of this part of the system reach their ultimate destinations by passing through certain of the cerebral nerves, particularly the vagus, as will be seen later.

The *sacral outflow* of the *parasympathetic system* comprises the sacral autonomies which emerge from the spinal cord by way of the roots of the second to the fourth sacral nerves and reach their destinations through the visceral branches of the sacral nerves.

The Vertebral Sympathetic System. On account of the confusion which has arisen owing to the loose use of the term "sympathetic" the author has found it desirable to employ the term "autonomic" for the whole system, and the words "vertebral sympathetic" for that part which is so well known, anatomically, as forming a bead-like chain alongside the vertebral column. The word "sympathetic" is sometimes employed to denote the whole system, and sometimes only the part, with the inevitable result that confusion arises. Here, therefore, the word "autonomic" is used to denote the whole of the system, and the words "parasympathetic" and "vertebral sympathetic" to differentiate its two main parts.

As thus defined, the vertebral sympathetic system, which can be seen with the naked eye in the greater part of its extent, forms the gangliated cords of human anatomy. It consists of two chains of gangliated cords, like two strings of beads, one on each side, immediately ventral to the vertebral

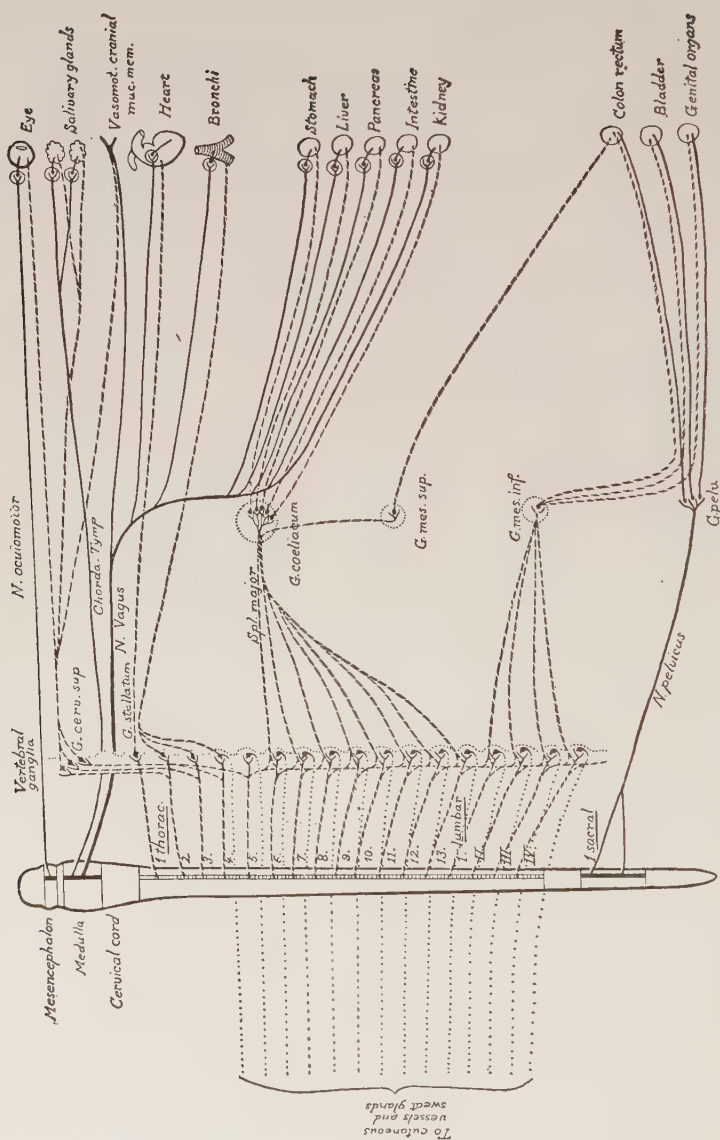


Fig. 13.—A diagram of the autonomic nervous system. (After Meyer and Gottlieb.)

column, and extends from the base of the skull to the coccyx. In the thoracic, lumbar, and sacral regions, the vertebral sympathetic ganglia usually correspond in number to the spinal nerve roots, though there is a tendency for the ganglia to be reduced slightly in number below that of the nerves. This reduction attains its maximum in the cervical region, where there are only three ganglia in each chain—superior, middle, and inferior—instead of eight. Most of the central (lateral) ganglia of the vertebral sympathetic system are connected with the spinal nerves by fine nerve connections, known as *rami communicantes*.

Ganglia Associated with the Vertebral Sympathetic System. Associated with the vertebral sympathetic system are three groups of ganglia—central or lateral, collateral, and terminal—and each ganglion is a cell station which establishes synaptic junctions.

The *central* or *lateral ganglia* are those just mentioned as arranged like a row of beads along either side of the vertebral column, and thus forming part of the “gangliated cords of the sympathetic” of human anatomy. These ganglia are all united together to form a chain which is easily seen on the cadaver on each side of the vertebral column, and they are, in addition, united to the neighbouring spinal nerves by the more delicate white and grey *rami communicantes* which are to be found on the lateral side of the ganglia. From the medial side the ganglia send off branches of distribution which pass either directly to the viscera, or indirectly through other ganglia, to the viscera. Prior to reaching the viscera these ganglionic branches of distribution often enter into large plexuses, such as the solar (coeliac) plexus.

The *collateral ganglia* are found in connection with the plexuses just referred to, that is, with the three great pre-vertebral plexuses situated within the thorax, abdomen, and pelvis, and named, respectively, the cardiac, solar (coeliac) and hypogastric. Into these plexuses also enter fibres from the parasympathetic system.

The *terminal ganglia* are located within the walls of the

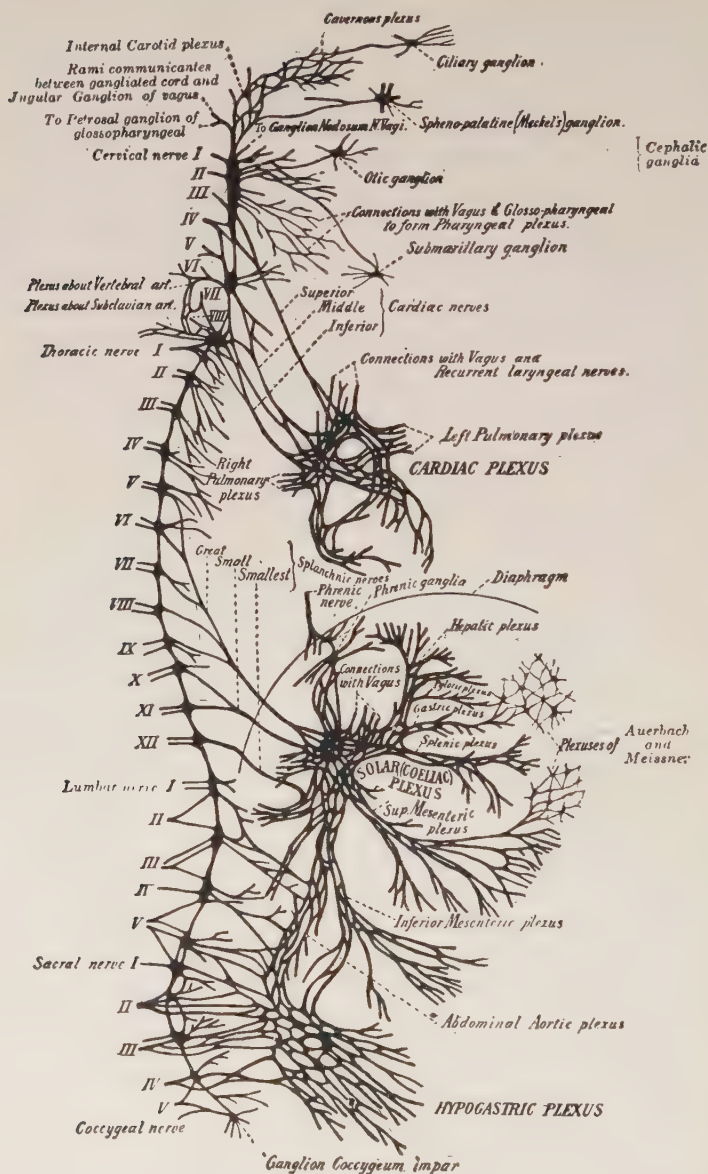


FIG. 14.—Scheme showing general plan of the coarser portions of the autonomic system and its principal communications with the cerebrospinal system. (After Flower, modified.) (From: Morris, "Human Anatomy.")

viscera and are not visible to the naked eye. They comprise such structures as the microscopic plexuses of Auerbach and Meissner in the intestines, and possibly many others.

The Neural Tube and Its Derivatives. Having now set forth the main anatomical parts of the central and autonomic nervous systems, it is necessary to consider briefly their mode of development.

The vertebrate nervous system is derived from the ectoderm

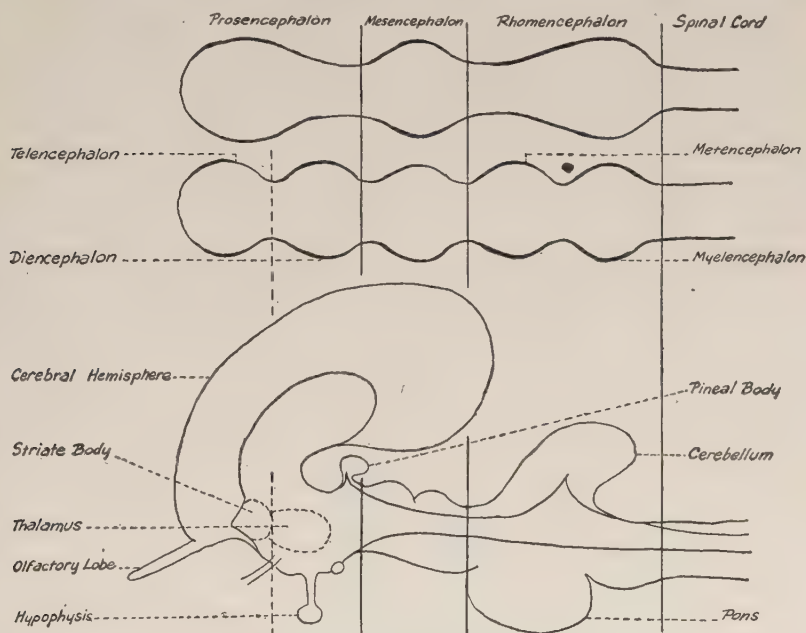


FIG. 15.—The neural tube and its derivatives.
See pages 51, 295, 426.

and first appears as the *neural groove* in the mid-dorsal line of the embryo. By a process of infolding this groove becomes converted into a canal—the *neural canal*.

At a very early stage of development the cephalic end of this neural canal becomes differentiated from the caudal end by its more rapid growth and expansion. As a result of this expansion three bulb-like swellings are formed which give rise to the *cerebral vesicles*, and are termed, in cranio-caudal order,

the *prosencephalon*, the *mesencephalon*, and the *rhombencephalon*. The most cephalic of these vesicles, the *prosencephalon*, becomes later divided into two secondary vesicles, termed the *telencephalon*, from which the cerebral hemispheres are subsequently developed, and the *diencephalon* or inter-brain. The second primary cerebral vesicle remains permanently undivided and later forms the mid-brain. The third primary cerebral vesicle, the *rhombencephalon*, also becomes divided into two secondary vesicles termed respectively, the *metencephalon* which gives rise to the cerebellum and pons, and the *myelencephalon* from which is developed the medulla oblongata.

The *cavity* of the neural tube persists throughout the whole of adult life as the ventricular system, whilst from its walls are developed the neurons, neuroglia, and other tissues of the brain and cord.

The several parts of the adult nervous system developed from the neural tube and its vesicles are as follows:

PRIMARY VESICLES	SECONDARY VESICLES	WALLS	CAVITY
Prosencephalon	Telencephalon	Cerebral cortex Corpora striata Rhinnencephalon Pars optica hypothalami.	Lateral ventricles Part of third ventricle
	Diencephalon	Epithalamus Thalamus Hypothalamus Metathalamus.	Greater part of third ventricle
Mesencephalon	Mesencephalon	Midbrain	Cerebral aqueduct.
Rhombencephalon	Metencephalon	{ Cerebellum Pons Medulla oblongata	Fourth ventricle
	Myelencephalon		
	Neural tube	Spinal cord	Central canal

Histogenesis of the Nervous System. The neural tube consists, at first, of a single layer of ectodermal cells, which

later proliferate and lose their cell boundaries. When the neural tube has closed, its walls consist of several layers of fused cells, bounded by an external and an internal limiting membrane. By a later proliferation of these cells, the lateral walls of the neural tube thicken and the cells become differentiated into three layers which are from within outwards, (1) an ependymal layer; (2) a mantle or intermediate layer, with many nuclei; and (3) a marginal or non-nuclear layer, which eventually give rise, respectively, to the ependymal cells lining the cavities of the ventricles and canals, the neurons and neuroglia, and the framework supporting the white columns.

From the germinal cells are derived, by a process of cell division, the ependymal cells of the ependymal layer, and the indifferent cells of the mantle layer. The latter undergo still further subdivision and so produce the spongioblasts and the neuroblasts. From the *spongioblasts* are derived the neuroglial or supporting cells of the nervous system, and from the *neuroblasts* are developed the true nerve elements of the nervous system—the neurons.

Whilst these several cellular elements are developing in the lateral walls of the neural tube, the ventral and dorsal surfaces are, in contrast, relatively thin, and do not expand equally with the lateral walls. Whilst the lateral walls are thus increasing in thickness, the *central canal* widens and its dorsal extremity assumes a lozenge shape, which later becomes reduced to a mere slit, whereas the ventral part persists as the central canal of the spinal cord. The widest part of the canal thus tends to divide the lateral wall of the neural tube into two parts, a dorsal portion, which is sensory or receptor in nature and is known as the *alar lamina*, and a ventral portion, which is motor or effector and is termed the *basal lamina*. As this lamination has clearly a functional significance its early appearance is of some importance. The lamination extends throughout the whole of the segmented portions of the neuraxis, and possibly also into some of the supra-segmental portions as well.

Development of the Receptor Neurons. The sensory, afferent, or receptor neurons are derived from neuroblasts which are, from the beginning, *outside* the neural tube. Prior

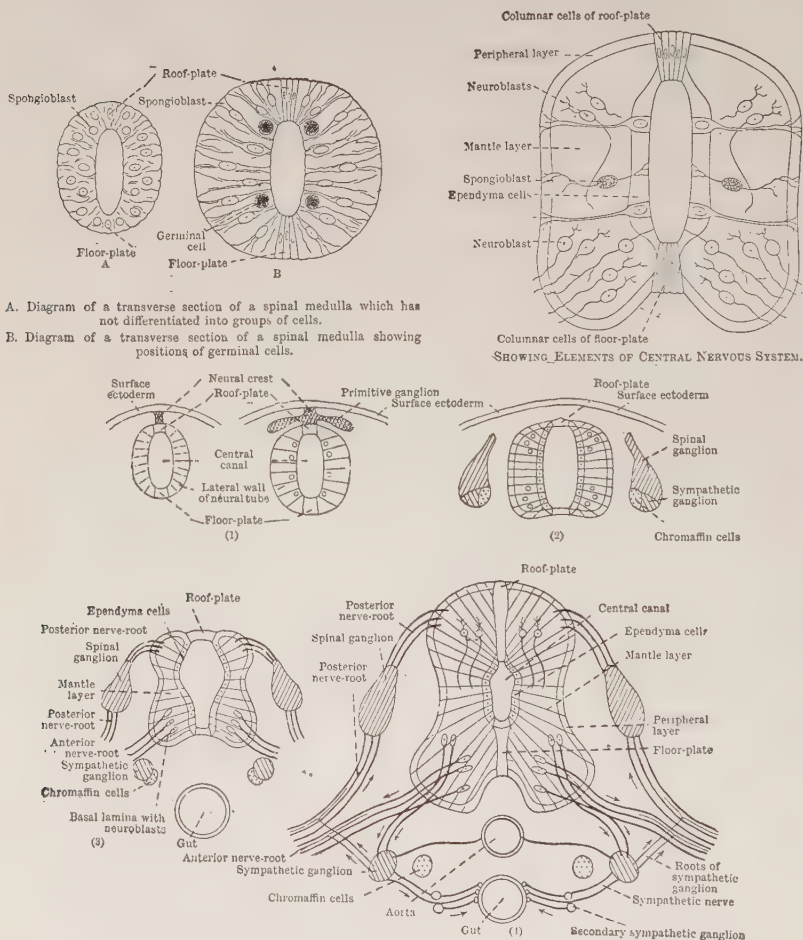


FIG. 16.—Histogenesis of the nervous system.

FIG. 16.—DIAGRAMS illustrating the formation of (1) the rudiments of the primitive ganglion from the neural crest. (2) The differentiation of different parts of the primitive ganglion into permanent ganglion root, sympathetic ganglion, and masses of chromaffin cells. (3) The formation of the anterior and posterior nerve-roots. (4) The differentiation of the walls of the neural tube into ependymal matter and peripheral layers. The cells of the primitive ganglion which form the primitive sheaths of the nerves are not shown in the diagrams. Histogenesis of the nervous system. (From: Cunningham, "Textbook of Anatomy.")

to the closure of the neural groove to form the neural tube, a ridge of ectodermal cells appears along the prominent margin of each fold. After the meeting and fusion of these folds,

the longitudinal ectodermal ridges also meet and fuse and so form the *neural crest*, which thus forms a wedge-shaped mass along the line of closure of the neural tube. From this neural crest are developed the dorsal root ganglia of the spinal nerves, as well as the central (or lateral) ganglia of the autonomic nervous system. The neural crest soon separates from the dorsal surface of the neural tube, and takes up its position in the angle between it and the myotomes, so that the various ganglia, or cell stations, of these receptor nerves, become dissociated from the neural tube.

The neuroblasts of these ganglia become bipolar by the development of a primary process at either end, but with subsequent development these processes fuse and the resultant neuron thus appears to be unipolar. From the apparently single process arise, by a T-shaped bifurcation, two processes, central and peripheral. The former grows centrally into the neural tube and there establishes synaptic contact with the developing nerve elements of the alar lamina. The latter grows peripherally as the receptor axon of a cerebrospinal nerve. Streeter's researches tend to throw doubt on this customary statement of the T-shaped division of the unipolar process. According to him some of these spinal nerve ganglion neuroblasts really lose one of their processes by absorption, whilst the other divides dichotomously in the manner indicated.

Development of the Effector Neurons. The motor, efferent, or effector neurons are developed from neuroblasts situated in the basal lamina. Their axons extend outwards, through the developing ventral nerve roots, come into contact with the peripheral processes of the developing receptor axons, and thus form a mixed spinal nerve. The *chain-cell hypothesis*, on the other hand, regards the axon as being developed, not from the cell-body as just described, but from other axon cells. The view does not appear to be in harmony with the neuron doctrine, or with experimental evidence.

Coincident with the appearance and growth of these effector neuroblasts, other neuroblasts within the mantle layer begin

to form the dorsal and lateral grey columns, and from some of these are developed those neurons which are to form the intersegmental and other spinal cord tracts.

As the axis cylinder of these neuroblasts grows and extends it becomes surrounded in some cases by a protective sheath which is also of ectodermal origin, and at this stage the axis cylinder appears to be surrounded by a number of spindle-shaped ectodermal cells, which have migrated from the neural crest. It is the presence of these cells which have given origin to the chain-cell theory of the origin of the axon. It seems more probable that it is these ectodermal cells which give rise to the neurilemma. The origin of the myelin sheath is uncertain, but it is of a fatty substance and appears earlier along receptor axons than effector—a fact of much significance.

The Autonomic Nervous System Ganglia. The ganglion cells of the autonomic nervous system are derived from the neural crest, and possibly also from the neural tube itself, whence they pass outwards by migration. From the ventrally situated segmented mass of the neural crest certain cells move outwards towards the side of the developing aorta, where some of them become grouped to form the central or lateral ganglia of the vertebral sympathetic. Others undergo still further migration and so come to form the collateral and terminal ganglia of the prævertebral and visceral plexuses. The ciliary, sphenopalatine, otic and submaxillary ganglia are probably formed by groups of cells which have migrated from that part of the neural crest which gives rise to the semilunar or Gasserian ganglion.

In connection with the development of these autonomic nerve ganglia, the migratory cells which form them appear, at first, as *sympathochromaffin cells*, from which are differentiated two varieties of cells; the smaller kind become later the *nerve cells* of the ganglia, the larger develop into the so-called *chromaffin organs*. These organs lie, at first, in depressions within the ganglia, but degenerate after birth, so that they can no longer be seen microscopically. Their place is subsequently occupied by chromaffin tissue.

Further Development of the Spinal Cord. The spinal cord of a 20mm. human embryo already possesses well-defined ependymal, mantle, and marginal zones. The mantle layer develops, as has been seen, into the grey matter of the spinal cord and contains the cell-bodies and the dendrons. The marginal layer develops into the white substance of the spinal cord by the growth, within it, of the axons of the neuroblasts located within the mantle layer. These form the various "tracts" which will eventually be located within the spinal cord, and as they myelinate at different embryological periods, it is possible, as stated, to determine the course and functions of these axons.

The *mantle layer of the alar lamina* develops into the dorsal grey column of the spinal cord and is receptor in function. Receptor fibres which grow into this layer from the neural crest either terminate within it, or ascend within the dorsal white columns to terminate within the alar plate of the myelencephalon. Most of the association fibres of the spinal cord, which run in the marginal layer, have grown out from neuroblasts developed within the dorsal grey column.

The *mantle layer of the basal lamina* gives rise to the ventral grey column of the cord, whence arise the axons of the effector cells which lie within it.

Further Development of the Cephalic End of the Neural Tube. At the end of the fifth week the cephalic or "brain" end of the neural tube of the human embryo is almost indistinguishable from that of any other vertebrate, except, perhaps, inasmuch as it shows a sharp flexure—the *cephalic flexure*—in the midbrain region. All five vesicles are visible and the separation between myelencephalon and spinal cord is just indicated by the commencing *pontine flexure*, whilst the optic cups have made their appearance as outpocketings from the prosencephalon, thus showing that the retinae are parts of the nervous system.

The Mammalian Brain. The mammalian brain is developed from the telencephalon and this is brought about by evaginations from the walls of that vesicle, so that

eventually, the paired masses, known as cerebral hemispheres, result.

In its earliest form the telencephalon comprises a thickened portion, effector in function, termed the *striate body*, and situated in the ventro-lateral wall of the telencephalon; a second part associated with the olfactory nerve, belongs to the *rhinencephalon*, whilst the remainder forms the roof or *pallium*. In the *cyclostomes* only a part of the rhinencephalon has been evaginated, and so the hemisphere merely comprises an olfactory bulb and lobe, and is hence not a true cerebral hemisphere. In the *amphibians* the evagination has proceeded further and involves the entire lateral wall, including the striate body and the pallium. In the *mammal* the evagination is complete and consequently true cerebral hemispheres make their appearance and the pallium becomes invaded by neurons and there is thus a neo-pallium, as well as an archi-pallium or smell brain.

CHAPTER V

THE NAKED EYE ANATOMY OF THE SPINAL CORD

Form and Position. The spinal cord is that portion of the central nervous system which lies within the vertebral canal, and extends from the great occipital foramen, where it is directly continuous with the medulla oblongata, to the medullary cone opposite the first or second lumbar vertebra. From the medullary cone a long, delicate thread, the *terminal thread*, prolongs the spinal cord on to the dorsal surface of the coccyx, and tends to fix it in position.

The spinal cord thus occupies the upper two-thirds of the vertebral canal, and is an elongated, cylindrical structure, slightly flattened ventrally and dorsally, with an average length in the male of 45cm., and in the female 43cm. It presents curvatures corresponding to those of the vertebral canal. The diameter of the spinal cord is less than that of the vertebral canal, and there is thus left a wide interval, occupied in the recent condition by the meninges of the spinal cord and the cerebro-spinal fluid, an arrangement which clearly provides for free movement of the vertebral canal without resulting shock to the delicate spinal cord.

Enlargements of the Spinal Cord. The diameters of the spinal cord are not uniform, because those portions of it which are specially concerned in the innervation of the limbs are larger than elsewhere, and as a result, two spindle-shaped enlargements are recognisable. Of these, the *cervical enlargement* extends from the third cervical to the second thoracic vertebra, and attains its maximum transverse diameter opposite the fifth or sixth cervical vertebra. This enlargement is, of course, due to the extra large number of neurons necessitated by the requirements of the superior extremity, and contained in this portion of the spinal cord.

The *lumbar enlargement* is similarly associated with the nerves of the inferior extremity. It commences opposite the ninth or tenth thoracic vertebra, attains its maximum diameter opposite the eleventh or twelfth thoracic vertebra, and terminates in the medullary cone.

Surface Markings. The surface of the spinal cord is divided into two nearly equal and symmetrical halves by means of two fissures, the anterior (ventral) median fissure, and the posterior (dorsal) median sulcus. Each lateral half of the spinal cord is still further subdivided into three columns or funiculi by means of two lateral furrows, the ventral and dorsal lateral sulci. In the cervical region, there is an additional furrow, the posterior intermediate sulcus.

Segmentation of the Spinal Cord. The spinal cord belongs to the primitively segmented portion of the neuraxis, and itself shows slight traces of this segmentation, inasmuch as it gives origin to thirty-one pairs of metameric nerves, and is thus composed of thirty-one segments. Each spinal cord segment gives attachment to one pair of nerves, and the division between these segments is arbitrarily made by an imaginary plane passing through the highest root filaments of each successive spinal nerve. Of these spinal cord segments there are eight in the cervical region, twelve in the thoracic, five in the lumbar, five in the sacral, and one in the coccygeal. To each one of these segments is attached a pair of spinal nerves, and hence the thirty-one pairs of spinal nerves are divided accordingly.

The Spinal Nerve Roots. Each one of the thirty-one pairs of spinal nerves is attached to the spinal cord by a series of delicate threads, the *fila radicularia*, which arrange themselves in two longitudinal lines, attached respectively to the dorso-lateral and ventro-lateral sulci of the spinal cord.

Those attached to the dorso-lateral sulcus form an almost uninterrupted series of root filaments, but all the root filaments from any given segment of the cord unite together to form the dorsal root of the corresponding spinal nerve.

From the ventro-lateral sulcus similarly emerge root fila-

ments, not so distinctly in line as the dorsal root fibres, which, from every given segment of the cord, unite to form the ventral root of the corresponding spinal nerve.

Both these nerve roots pass towards the corresponding in-

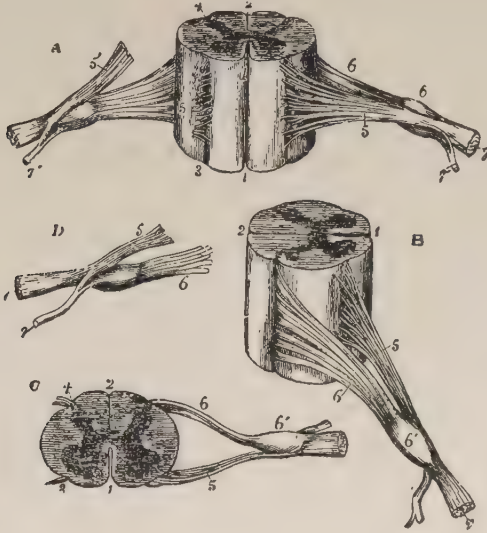


FIG. 17.—Different views of a portion of the spinal cord from the cervical region with the roots of the nerves. Slightly enlarged. (Allen Thomson.) In A the anterior or ventral surface is shown, the ventral nerve-root of the right side having been divided; B, view of the right side; C, the upper surface; D, nerve-roots and ganglion from below. 1, ventral median fissure; 2, dorsal median fissure; 3, ventro-lateral impression, over which the bundles of the ventral nerve-root are seen to spread (too distinct in figure); 4, dorso-lateral groove, into which the bundles of the dorsal root are seen to sink; 5, ventral root; 5', in A, ventral root divided and turned upwards; 6, dorsal root, the fibres of which pass into the ganglion, 6'; 7, united or compound nerve; 7', dorsal primary branch, seen in A and D to be derived partly from ventral, partly from dorsal root. (From: Luciani, "Human Physiology.")

tervertebral foramen, pierce the dura mater, receiving from it a sheath, and by their union form a *spinal nerve*. The direction of these roots gradually passes from a horizontal to an almost vertical, position, consequent on the fact that the

spinal cord is not the same length as the vertebral canal. It thus follows that the last thoracic and all the lumbar, sacral, and coccygeal nerves pass vertically, for some considerable distance, within the dura mater, and thus form an appearance known as the *cauda equina*, in the midst of which the terminal thread may be distinguished as a glistening, silvery streak.

These relations of the spinal cord and the cauda equina to the vertebral column are of practical importance. In lumbar puncture the needle is introduced into the subdural space *below* the termination of the spinal cord, but into the region occupied by the cauda equina. It is further of importance to differentiate between lesions affecting the lower part of the spinal cord, and those involving only the nerves of the cauda equina, because the former are irreparable, and the latter may undergo regeneration. It is, therefore, of clinical importance to know the position of the various spinal cord segments relative to the vertebræ.

Structure and Functions of the Spinal Nerve Roots. It is now many years since Sir Charles Bell discovered that the dorsal nerve roots fulfilled functions different from the ventral, and he clearly proved that the former were generally "sensory" in function, and the latter "motor." But it is now further known that neurons belonging to both the central nervous system and the autonomic pass through these roots to and from their several destinations, that is, two totally different functional systems make use of these pathways, and hence the construction of these spinal nerve roots is more complicated than even as indicated by Bell's important discovery.

The spinal nerve roots are composed of neurons passing to and from the viscera, and to and from portions of the body other than viscera, hence there are included visceral or splanchnic neurons and bodily or somatic neurons, and it consequently follows that through these nerve roots pass nerve elements belonging to four functionally different systems, thus:

Through dorsal nerve roots.

Visceral receptor or afferent neurons.

Somatic receptor or afferent neurons.

Through ventral nerve roots.

Visceral effector or efferent neurons.

Somatic effector or efferent neurons.

Visceral Receptor or Afferent Neurons. Viscera are capable of responding to chemical, physical, and mechanical stimuli, here collectively termed *entero-ceptive*. These entero-ceptive impulses from viscera are transmitted centrally over

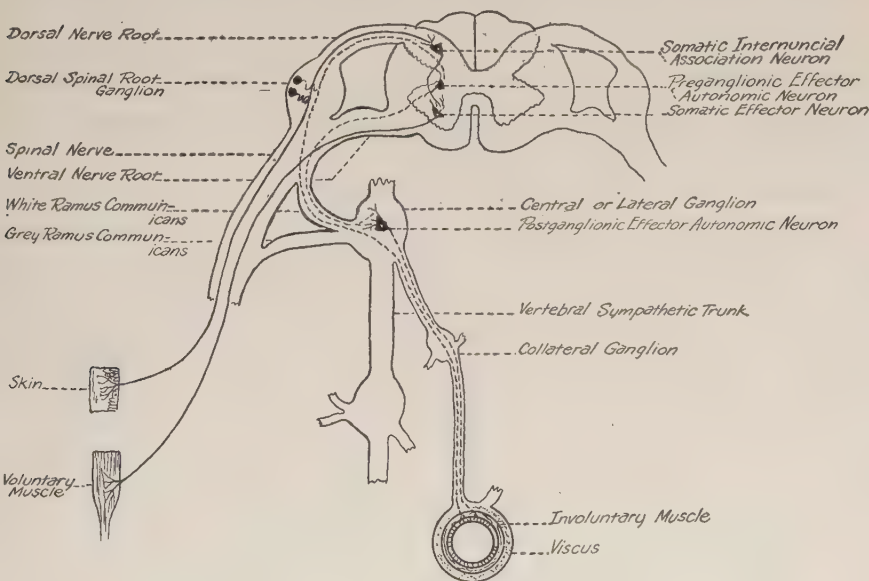


FIG. 18.—Some of the structural elements of the spinal nerve roots.

See pages 47, 62, 81, 89, 96, 123.

long-axoned neurons which have their cell-stations in the dorsal spinal root ganglia. It appears to be impossible, in the present state of neurological knowledge, to trace the course of these neurons with that precision which is essential to clinical practice. In the absence of such definite knowledge it can only be assumed that the *peripheral* process passes uninterruptedly from the viscus to the cell-station, and that it does so through the ramifications of the anatomical sympha-

thetic system into the vertebral sympathetic chain, thence through the corresponding white ramus communicans into the spinal nerve, and on into the dorsal root of that nerve to the cell-station in the ganglion. The *central* process passes from the cell-station through the dorsal nerve root into the spinal cord, where it terminates in the vicinity of the lateral grey column by establishing synaptic contact with the pre-ganglionic effector neuron. Entero-ceptive impulses from thoracic and abdominal viscera appear to pass centrally through the white rami of the thoracic and upper lumbar nerves, as also through the second, third, and fourth sacral nerves. The axons over which these visceral impulses are transmitted belong to the vertebral sympathetic system and appear to be of very different sizes and to include large and small myelinated axons, as well as non-myelinated axons. (Ranson.) Other entero-ceptive impulses also traverse receptor neurons associated with the parasympathetic system, but these enter the neuraxis through cerebral nerves and not spinal, and so do not fall to be considered here. It seems, however, to be very important to note that receptor impulses from viscera traverse the vertebral sympathetic system in the manner indicated, because the fact appears to be frequently forgotten and it is impossible to explain the occurrence of many clinical phenomena associated with visceral disease if the fact is so forgotten. Visceral impulses traversing these routes serve to initiate visceral reflexes—hence their importance—but do not usually rise to consciousness, and so these general visceral sensations are vague and poorly localised. Further, visceral sensibility is primitive in character and is entirely lacking in tactile impulses and almost entirely in thermal sensation, nor can pain be induced by pinching or cutting the thoracic or abdominal viscera. On the other hand, if the visceral impulses be of an aberrant character, or of too powerful a nature, as in disease or functional visceral disorder, the stimuli “overflow” their normal arcs, cross the synapses into somatic neuronic arcs, and so rise to higher levels with the production of pain and reflex muscular actions. Only in this way can the

acute pain generated by the passage of a calculus along the ureter be explained. Here the receptor ramifications of the peripheral processes concerned are abnormally stimulated and the impulses generated "overflow" into somatic neurons and so reach the higher centres, whereas under normal conditions the impulses generated should be confined to the autonomic arcs concerned.

Somatic Receptor or Afferent Neurons. Through the dorsal spinal nerve roots are also transmitted receptor axons from structures other than viscera. These structures comprise muscles, tendons, bones, joints, skin, and so on, and are collectively termed *somatic*. Sherrington has pointed out that all somatic receptor impulses fall into one or other of two great groups—proprio-ceptive from the locomotor system, and extero-ceptive from stimuli arising outside the body and from the surface of the body, that is, the skin. Each group requires special receptor organs designed to respond to the suitable stimulus, and for each there are special groups of neurons transmitting these impulses centrally, with special paths or tracts within the spinal cord. Of these two systems, all the neurons which enter the spinal cord have their cell stations in the dorsal root ganglia, and the general course of the peripheral and central axons resembles that previously described. It is further known that voluntary muscles have a double innervation, autonomic and somatic, and that the receptor neurons from both enter the spinal cord through the dorsal spinal nerve roots. It is, therefore, clear that the constituent elements of an entering dorsal nerve root are much more complicated than was originally supposed, and much work has recently been devoted to the study of these constituent elements, as well as to their histological construction.

Visceral Effector or Efferent Neurons. The visceral effector or efferent neurons have their cell stations in the lateral grey column of the spinal cord, whence their axons emerge through the ventral nerve roots of the corresponding spinal nerve. They pass thence to viscera through the rami communicantes into the autonomic system, and terminate in the

ganglia of that system by establishing synaptic contact with the secondary or post-ganglionic neurons.

Somatic Effector or Efferent Neurons. The somatic effector or efferent neurons (the lower motor neurons or the final common effectors) have their cell-stations in the ventral grey column of the spinal cord. These are of the multipolar Golgi Type I variety, and the axons from these cells pass out through the ventral nerve roots and end on the muscle fibres in special motor end-plates. The nerve impulse so transmitted to the muscle initiates contraction of the muscle, whilst the postural tone of the muscle is maintained by the effector neurons of the autonomic system. In each case the anatomical path pursued by both the somatic and autonomic voluntary muscle innervation is through the ventral root of the spinal nerve and thence to the final termination by the appropriate spinal nerve. The somatic nerve element is usually myelinated, whilst the autonomic muscular nerve is non-myelinated.

The Spinal Cord in Section. In transverse section and as seen with the naked eye, the spinal cord consists of two kinds of tissue, white and grey. The grey matter is made up of the cell-bodies of neurons, dendrons, myelinated and non-myelinated axons, and many small blood vessels. The white matter, on the other hand, consists chiefly of myelinated axons, and both forms of tissue are supported in neuroglia.

The Grey Substance of the Spinal Cord. The grey substance of the spinal cord has, in its entirety, the form of a fluted column, which is everywhere surrounded by white matter and is thus separated from the surface. In transverse section it assumes the form of the letter H, and presents for examination a broad ventral column, a narrow dorsal column, a smaller lateral column, and a transverse bar connecting the grey matter of the two sides, and termed the grey commissure. The term "horns" is frequently applied to these columns, but as they form a continuous mass throughout the whole length of the spinal cord, the term "column" is obviously better.

The *dorsal grey column* is relatively long and narrow and

nearly touches the surface at the dorso-lateral sulcus. It comprises a constricted portion, the *neck*, a pointed dorsal extremity or *apex*, and an intermediate expanded portion, the *head*. The apex of the dorsal grey column differs considerably from the rest of the grey substance of the cord, as

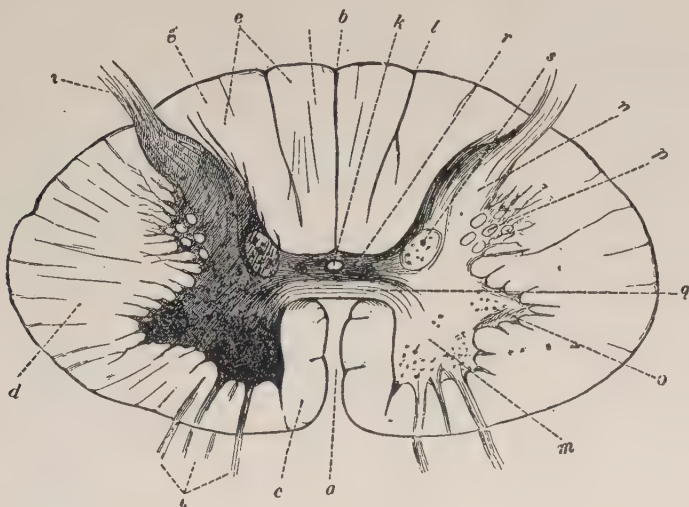


FIG. 19.—Diagrammatic transverse section of spinal cord. (Erb.)
a, fissura longitudinalis ventralis; *b*, *f*, l. dorsal; *c*, ventral column; *d*, lateral column; *e*, dorsal column; *f*, funiculus gracilis; *g*, funiculus cuneatus; *h*, ventral; *i*, dorsal root; *k*, central canal; *l*, sulcus intermedius dorsalis; *m*, ventral horn; *n*, dorsal horn; *o*, tractus intermedio-lateralis; *p*, processus reticularis; *q*, white or ventral commissure; *r*, grey or dorsal commissure; *s*, Clarke's column or columna vesicularis. (From: Luciani, "Human Physiology.")

it is composed of a lighter-hued and more transparent material, known as the *substantia gelatinosa of Rolando*, which it is very difficult to stain by ordinary neurological methods.

The *ventral grey column* is short, thick, and blunt, and does not reach the surface of the cord, but projects towards the ventro-lateral sulcus. It gives origin to the ventral roots of the spinal nerves and is thus effector in function.

The *lateral grey column* juts out from the lateral aspect of the grey matter nearly opposite the grey commissure. It is best marked in the lower cervical and thoracic regions, because

it is the cell-station of autonomic visceral effector neurons, and these are chiefly found in the regions mentioned.

The two grey columns are connected together across the middle line by a transverse bar of grey matter, the *grey commissure*, which is traversed by the central canal of the cord, and is thus divided into a ventral and dorsal grey commissure.

In the cervical region the grey matter is not so sharply marked off from the white substance as elsewhere, but on the lateral aspect of the grey substance, in the angle between the ventral and dorsal columns, fine bands of grey substance radiate out into the white substance, forming a network, termed the *reticular formation*, the meshes of which enclose islands of white substance, and hence the name. This reticular formation becomes much more prominent when traced upwards into the medulla, pons, and midbrain.

The White Substance of the Spinal Cord. The white substance of the spinal cord is composed almost entirely of medullated axons running, for the most part, longitudinally. It thus presents to the naked eye a homogeneous, undifferentiated appearance, and requires very special methods for the tracing and study of its composite axons. It assumes the form of a thick mantle everywhere surrounding the grey matter, and separating the latter from the surface, an arrangement which obviously here precludes any great additions to the cell bodies of the grey matter. In each lateral half of the spinal cord the white matter is described as consisting of three great columns or *funiculi*, ventral, lateral, and dorsal. The ventral funiculus lies between the ventral nerve roots and the ventral median fissure. The lateral between the ventral and dorsal nerve roots, and the dorsal funiculus lies between the dorsal nerve roots and the dorsal median fissure.

Reciprocal Alterations in Grey and White Matter. It is obvious that wherever large numbers of medullated axons are entering the spinal cord there will be a corresponding increase in the amount of white matter, and that wherever function demands an increase in the number of cell-stations in the grey matter, as in the cervical and lumbar enlargements, that

the grey matter will be correspondingly slightly larger. These reciprocal alterations in the relative amounts of grey and white matter in the spinal cord alter, therefore, the appear-

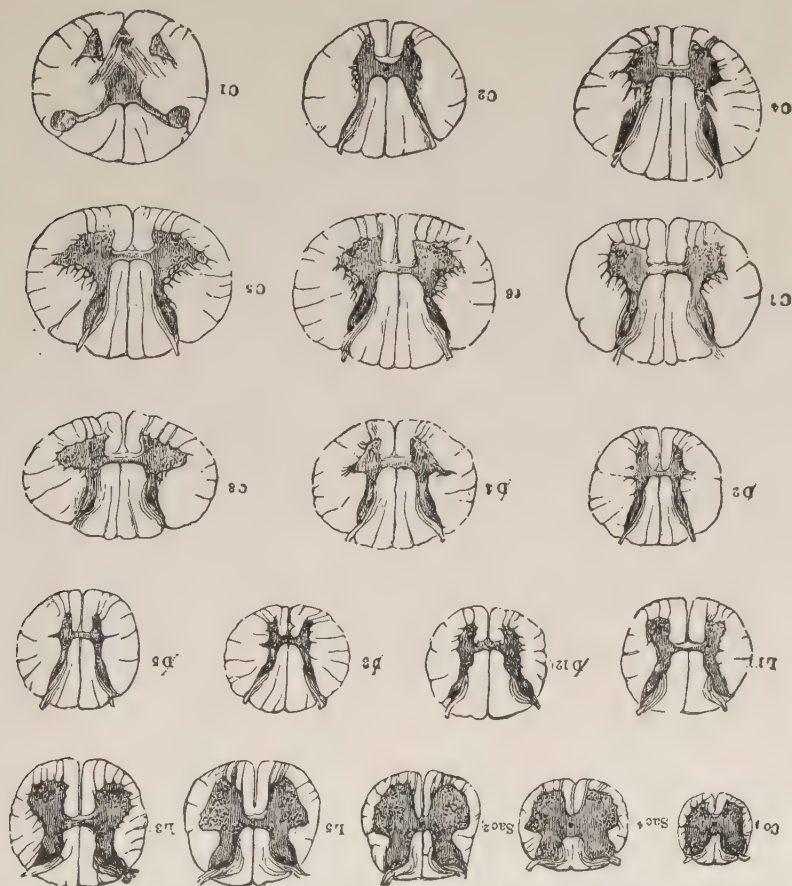


FIG. 20.—Transverse section of spinal cord at different heights. (W. R. Gowers.) Twice the natural size. The letters and numbers indicate the position of each section; Co, at level of coccygeal nerve; Sac. 4, of 4th sacral; L3, of 3rd lumbar, and so on. The grey substance is shaded dark, and the nerve-cells within it are indicated by dots. (From: Luciani, "Human Physiology.")

ances of grey and white matter in different segments of the cord. So long as the functional significance of these slight alterations is understood, the actual morphological appear-

ances are relatively unimportant, though it necessarily follows that it is quite possible, by these differences, to refer almost any section through the spinal cord to its correct segment.

General Functions of the Spinal Cord. In its primitive form, as seen in the lowest vertebrates, the spinal cord is little more than a central nerve ganglion for the control of purposeful, unconscious, reflex activities essential to the maintenance of the animal's life. As other and higher parts are added



FIG. 21.—Knee-jerk. A, the dotted line indicates the movement produced by tapping the patellar tendon; B, the same obtained by a hammer when it does not occur readily in the usual way. (From: Luciani, "Human Physiology.")

to the neuraxis the spinal cord adds, to its reflex activities, that of the conduction of the nerve impulses from the several organs to the higher brain centres, and both these functions are retained in man.

By a *reflex action* is meant the *involuntary* and often unconscious production of activity in some peripheral effector tissue, in response to some incoming stimulus conveyed centrally over a receptor neuron. Such a reaction involves certain structural elements, namely, those which make up the neuronic arc, and have been described on page 3. The spinal cord subserves many of these simpler reflexes, but the more complicated of them may involve the spinal cord and brain.

Speaking generally, the higher the animal is in the evolutionary scale, the less important does the spinal cord become as an instrument of reflex actions, because its more primitive functions tend to be replaced or obscured by the higher nerve centres. This naturally attains its highest development in man, where the reflex activities of the spinal cord of the lower animals are largely absorbed in the greater activities of the brain. That the primitive mechanism is retained in the spinal cord of man is shown, however, by the fact that after complete transverse lesions of the spinal cord, provided there be no further destruction of the remaining neurons by sepsis, many reflex actions, such as the emptying of the bladder, and so on, can still be carried on. In man, therefore, some of the spinal cord reflexes of the lower animals are, as it were, dormant, but, given time, are quite capable of functioning.

It has been seen that the spinal cord is connected with both the somatic and autonomic nervous systems, and thus mediates some of the reflex activities of both systems. The knee-jerk is an example of the former, and the contraction of the stomach in response to the ingestion of food of the latter. Through its association with the *autonomic nervous system* the spinal cord performs many varied and important functions essential to life and of a purely reflex or unconscious character. Through its association with the peripheral spinal nerves of the *central nervous system*, the cord performs many somatic reflex acts, in addition to forming a most important pathway to and from the brain, for all incoming receptor impulses, and the outgoing effector ones. As the phenomena and maintenance of life depend upon the correct transmission of these unconscious and conscious impulses it is essential, before disease can be treated, that they should be understood, and their paths and reflex arcs through the nervous system followed, and to do so necessitates a close study of the neurons concerned.

CHAPTER VI

THE AUTONOMIC NERVOUS SYSTEM

Nomenclature. There is no part of the nervous system with a more confusing, or confused, terminology than the one now to be described. Grafted on to an ignorance of the functions to be subserved is an often largely obsolete terminology, hence the confusion. In view of the great importance of the system in the study and treatment of disease it is necessary to employ a nomenclature which will be more in accordance with modern researches than has hitherto been the case.

Anatomists have long been familiar with a system of ganglia, nerves, and plexuses, lying outside the spinal cord, through which are innervated the viscera, glands, heart and blood vessels, as well as smooth muscle generally, and to which was applied the term *sympathetic nervous system*. For this system alternative names have arisen, such as, visceral nervous system, vegetative nervous system, and the system of the extended vagus. Recently, and as a result of more extensive research, Langley and Gaskell have suggested the term *autonomic nervous system*. The word "autonomic," although now much used in preference to the older "sympathetic," is however, frequently mis-applied; thus it is sometimes employed to denote the whole system, sometimes only the part, as when used as a synonym for the parasympathetic portion, and sometimes, as by Ranson, to denote only the effector side of the autonomic mechanism.

As the system works in health largely automatically, it is, perhaps, better to employ the term *autonomic* for the whole, and the two opposed effector sides of the system can then be differentiated as *parasympathetic* and *vertebral sympathetic*, whilst it is not to be forgotten that to each of these

effector sides of the system there must be a receptor side, though this last fact appears to be frequently overlooked, with the result that visceral disturbances often become difficult to understand.

The following table summarises the synonyms now in use:

The sympathetic nervous system,
or
The involuntary nervous system,
or
The visceral nervous system,
or
The vegetative nervous system,
or
The Autonomic Nervous System.

The parasympathetic,	The vertebral sympathetic,
or	or
The autonomic,	The sympathetic,
or	or
The system of extended vagus,	The ganglionated sympathetic,
or	or
The enteral system,	The thoraco-lumbar system.
or	
The cranio-sacral system.	

For reasons already set forth the terms *autonomic nervous system* will herein be strictly used to designate the whole system, and the terms *parasympathetic* and *vertebral sympathetic* to denote its two opponent effector systems. Both of these opponent effector systems will be further assumed to possess receptor limbs to their arcs, over which it will be further assumed that visceral impulses are continually being transmitted centrally, and this assumption will be made notwithstanding that the neuronie paths concerned are not, in many instances, substantiated either histologically or experimentally. The assumption is, however, in accordance with the whole principle of construction of the neuronie arc and

the nervous system, and is necessitated by Sherrington's investigations on the central transmission of entero-ceptive or visceral impulses. Further the central paths traversed by some of these receptor visceral neurons are quite well established. The fact that such paths are not everywhere known does not imply their absence in some viscera and their presence in others. It merely denotes an incomplete knowledge.

Importance of Incoming Receptor Nerve Impulses. Every living animal, man included, is endowed with a varying number of "senses," by means of which the animal is informed of the state and needs of its own body, as also of the conditions of the physical world around it, in so far as it possesses sense organs for the purpose. It is thus enabled to react to its environment in the manner best suited to its mode of life. In the case of an organism like the earthworm, these "senses" are simple and few. In the case of man they are many and complex, but the nerve mechanism involved is essentially the same in both, namely, the neuronie arc.

The sense organs themselves are termed "receptors" and they vary in structural complexity from the naked axis cylinders to extremely complicated pieces of apparatus like the organ of Corti for hearing. These receptors are attuned and constructed to respond to some particular stimulus, chemical, physical, thermal, mechanical, and the like. They transmit the stimulus to their own series of neurons which are thus aroused to discharge nerve impulses of a receptor character, that is, those which will cross a synapse in a central direction. These receptor impulses are *continually* being discharged into the human brain, even from before birth to death, and are ceaselessly modifying the neuronie pattern of the brain. Their complete cessation is synonymous with death, their partial cessation with sleep or unconsciousness, and their insufficiency with idiocy—idiocy from deprivation of the senses.

Sherrington's work enables us to recognise in man three great groups of receptors—entero-ceptors or visceral, proprio-

ceptors or locomotory, and extero-ceptors from without, which are broadly, though not accurately, indicative of the three great evolutionary phases through which the nervous system has passed. These may be summarised thus:

The *vegetative evolutionary level* is represented by the entero-ceptors from the viscera transmitted centrally through the autonomic nervous system.

The *sensori-motor level* is represented by the proprio-ceptors transmitted through the spinal cord and the segmented portions of the nervous system.

The *psychic level*, that is the level of the delayed response to the stimulus, is represented by the extero-ceptors of the supra-segmental portions of the central nervous system, and attains its maximum development in the brain of man.

Effector Responses Follow Receptor Impulses. Every receptor impulse must be followed by an appropriate effector or motor response, which is either an immediate one, or is delayed. In the case of the simpler organisms, such as the earthworm and spinal cord animals, the effector response to the receptor impulses is not only immediate, but its nature can be predicted with certainty. This is always the case where there are but few internuncial neurons interposed between the receptor and effector limbs of the neuron arc, for the obvious reason that there is little or no resistance to the passage of the nerve impulse through the whole arc. With successive evolutionary additions to the nervous system, culminating in the mental manifestations of the human brain, the number of interposed internuncial neurons becomes enormously increased, so that the effector responses are now either inhibited altogether, delayed, suppressed, or passed quickly through alternative shorter arcs, and it is thus no longer possible to forecast with precision the exact character of the response to the stimulus. It is of the simpler neuron arc reflexes that the autonomic nervous system of man is largely composed, because the results to be brought about are essential to life and must be rapidly and automatically effected. It is, therefore, obviously desirable to study these simpler autonomic

reflex neuronic arcs first, before proceeding, as is usually done, to the much more complex ones of the central nervous system.

General Functions of the Autonomic Nervous System.

The general functions of the autonomic nervous system are admirably summarised by Langdon Brown in the following words: "When we consider the results of sympathetic (autonomic) stimulation, we see that they all serve to activate the body for a struggle, and to increase its powers of defence. The *pupil* dilates to increase perception of light: the *heart* beats more quickly and more forcibly to supply the muscles with blood: the blood vessels in the visceral area constrict, raising the blood-pressure and driving the blood from the digestive area, whose functions are simultaneously inhibited, into the skeletal and cardiac muscles, the lungs, and the brain."

The relatively simpler neuronic construction of the autonomic nervous system, as compared with the more complex one of the central nervous system, enables it to produce generalised, widespread, and diffuse effector responses to the appropriate and minimal receptor stimuli as easily and speedily as possible, whereas the more complex neuronic arcs of the somatic nervous system provide for more localised and accurate effector responses to the stimulus.

The Receptor Organs of the Enteroceptive System. The receptor organs of the visceral system appear to be, in most, if not all cases, the naked axis cylinders of the receptor neurons themselves, which ramify between the lining and other cells of the viscus concerned. They respond only to stimuli arising within the viscera, that is, to chemical, mechanical, physical, and other minimal stimuli produced by glands, viscera, blood-vessels and involuntary muscles generally, and are thus specially concerned with the vital reflex phenomena of the processes of nutrition, excretion, etc.

It is not, as yet, clear whether all the coats of a viscus, such as the mucous, submucous, muscular, and serous of the alimentary canal, are provided with one common receptor neuron, or whether each coat has its own independent receptor neuron, nor is it clear whether there are other visceral

receptor organs besides the naked axis cylinders. In the absence of histological proof to the contrary it seems more probable that the different visceral coats are provided with their own "free nerve-endings"—an unfortunate term,—inasmuch as these are really the commencements of the neuronie arcs concerned, at least in so far as the transmission of impulses is concerned.

Nature of Visceral Sensations. Whatever the exact histological mode of the central conduction may be it is certain that viscera are constantly transmitting entero-ceptive impulses centrally, and these are essential to life. Amongst the somewhat vague sensations produced may be mentioned those of hunger, thirst, nausea, sensations of respiratory suffocation, circulatory sensations of flushings and heart panic, sexual sensations, impressions of the distension of cavities, and others even more obscure.

These sensations, aroused by the appropriate stimulation of the visceral receptor "free nerve endings" typically call forth visceral responses, that is, the effector responses or adjustments are wholly within the body, and are performed mechanically and unconsciously, though a few may be controlled at will. These visceral responses to the receptor stimuli are inborn, require no practice or education for their performance, are innate and invariable in character, and are essentially similar in all members of the race or species. They are further strictly adjusted to the mode of life characteristic of the species.

The physiological phenomenon of *hunger* is usually attributed to pronounced motor activity of the stomach, that is, to a preponderating discharge of nerve impulse over the effector side of the autonomic arcs concerned. This explanation, however, makes no mention of the receptor impulses from the stomach which have overstimulated the effector limbs of the gastric neuronie arcs. That these stimuli really do arise in the stomach, and are not due to any general change in the nutrition of the body as a whole appears to have been proved by physiological experiment. There are doubtless other fac-

tors entering into the gastric sense besides those of receptor stimuli from the organ itself, which is thus a complex one, but the neurological conception of receptor stimuli transmitted normally in health, and in an aberrant form in disease, from the stomach is of very considerable practical and clinical importance. For example, in *acute gastritis*, errors in diet produce an aberrant gastric secretion which, in its turn, abnormally overstimulates the receptor organs, and thereby transmits aberrant nerve impulses over to the effector limbs of the arcs, and hence the pain, eructations, and vomiting. These effects and their causes are still more evident in the toxic phenomena produced by the swallowing of such poisons as phosphorus, corrosive sublimate, ammonia, and arsenic. In all these, and similar instances, the aberrant stimuli first seriously disturb the gastric autonomic arcs, and later the somatic arcs, and thus interfere with the bodily health as a whole.

The phenomenon of *thirst* is generally believed to be induced by a drying of the pharyngeal mucous membrane, accompanied by other more general bodily changes. This appears to affect the "free nerve endings" of the pharyngeal receptor neurons, and thus alters the nature of the impulses over the arcs concerned. That this is the correct neurological explanation appears to be supported by the fact that thirst may be relieved by moistening the pharyngeal mucous membrane without actually swallowing any fluid.

Sexual sensations are apparently aroused, *primarily*, by tension or distension of the glands concerned, though but little is known of the receptor organs concerned or of the nerve routes followed, and *secondarily* by many other senses. After puberty it is certain that the testis or ovary transmits enteroceptive impulses centrally, which are followed by effector responses, which not infrequently profoundly modify the mental outlook of the individual. Whilst the normal physiological transmission of these sex enteroceptive impulses is usually completely overlooked, as is also the mental effect produced by these impulses, the lack of such impulses quickly

manifests itself clinically. When an otherwise normal adult develops a premature loss of sexual power, or erroneously conceives that such is the case, he frequently suffers from a very profound mental depression, which should not be the case were the impulses being normally transmitted. If these phenomena occur in the ament they may even be attended by actual mental disorder.

As an example of the purely automatic character of these visceral neuronie arcs may be mentioned the taking of food. The ingestion and preliminary mastication of food are generally voluntary acts whose various processes are, or may be, controlled at will. Once the bolus of food has passed into the œsophagus, the further work of swallowing, digestion, and assimilation, is entirely under the control of the autonomic nervous system, and is thus involuntary and unconscious.

In addition to the foregoing *general visceral receptor* "senses" there are the *special visceral receptor* senses of taste and smell, each provided with very definite and well-known receptor organs. The receptor organs for *taste* are the well-known histological taste buds found on the tongue and adjacent parts, and known to respond to chemical stimulation. The receptor organs for *smell* are the olfactory bipolar sensory or receptor cells, excited by chemical stimulation. The olfactory sense is of great antiquity and is profoundly modified in different animals in accordance with their requirements. In man the sense has almost disappeared and is not to be compared in acuity with that, for example, of the dog.

Differences Between the General and Special Visceral Receptors. Between the general and special visceral receptors there are some important differences. The former have no highly specialised receptor organs, the nerve routes are entirely autonomic, and the effector reactions are performed unconsciously. The latter are provided with very highly specialised receptor organs, the nerve routes are entirely somatic, and the resultant reactions are conscious and voluntary.

The Visceral Effectors. In accordance with the general neurological principles of the reflex arc, there must be some

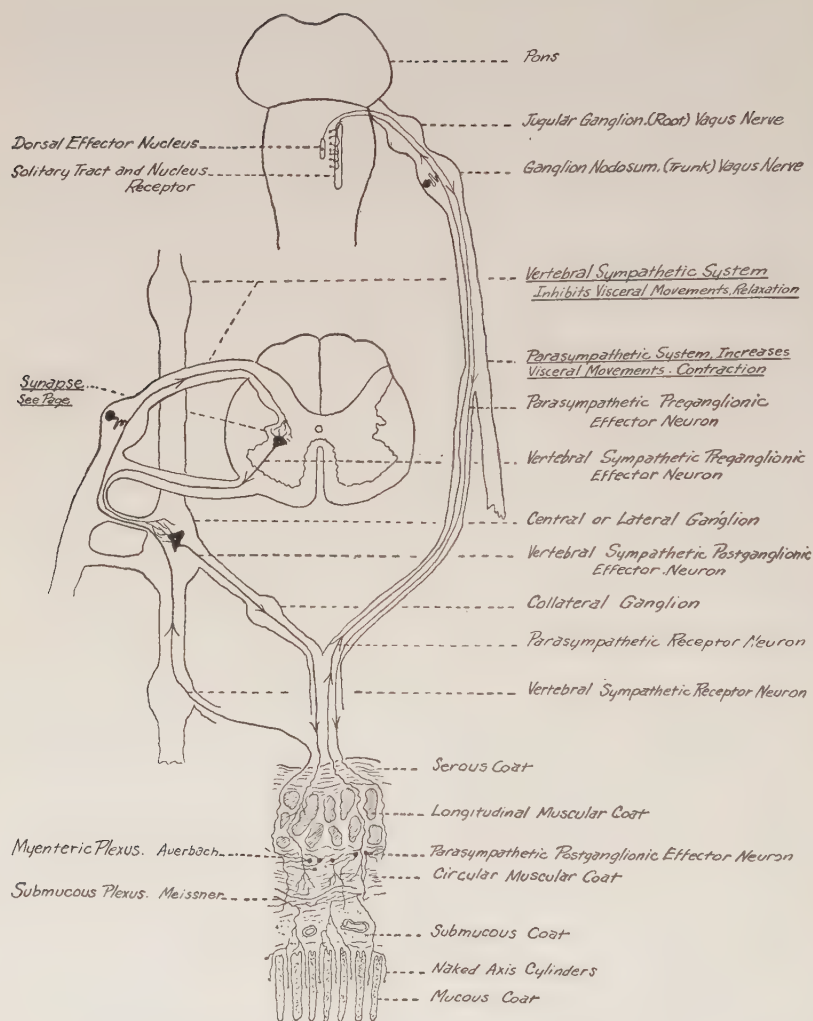


FIG. 22.—Diagram to illustrate the principles underlying visceral innervation in health and disease. See pages 45, 63, 65, 74—99, 123, 254, 263.

motor or effector response on the part of the viscera to the receptor stimuli, and as these are often very obvious under diseased conditions this side of the visceral arc is much better understood, clinically, than the receptor. It is too frequently forgotten that the reverse is equally true. Effector responses require previous receptor stimuli, and this side of the visceral arc is often overlooked, particularly in disease.

On the visceral muscles, which are usually of the involuntary, unstriated variety, but may be striated, as in the heart, the effector neuron ends in the appropriate end-organ, and the effector impulse traverses at least two effector neurons—pre-ganglionic and post-ganglionic. It is a mistake to regard the pre-ganglionic effector neuron, as is sometimes done, as a connectant neuron. Similar effector neurons pass to other visceral elements, such as glands and the like.

Neuronic Arcs of the Autonomic Nervous System. It has long been known that many of the spinal nerves are connected with many of the ganglia of the vertebral sympathetic trunk by fine nerve connections, known as *rami communicantes*.

After emerging from the intervertebral foramen every spinal nerve is connected with the vertebral sympathetic trunk of its own side by one or more *grey rami communicantes*, through which it receives fibres from the vertebral sympathetic trunk and the autonomic system generally. The thoracic and upper lumbar spinal nerves also contribute a branch, the *white ramus communicans*, to the vertebral sympathetic trunk, through which run the pre-ganglionic effector fibres, and possibly others which utilise it as a pathway. The second, third, and fourth sacral spinal nerves also give off white rami communicantes which pass directly into the pelvic plexuses. These rami communicantes lie on the lateral side of the vertebral sympathetic trunk, and as the latter tends to approach the middle line in its descent, they tend to be longer the lower they are. These rami communicantes are not to be confused with the peripheral branches of the vertebral sympathetic trunk, which come off on the medial side and pass to the ganglia of the prævertebral plexuses. It

will be obvious that those regions of the spinal cord where the white rami communicantes are deficient are those primarily concerned with the limb plexuses, that is, the cervical and lumbar enlargements.

These rami communicantes form the links between the spinal cord and the more outlying parts of the vertebral sympathetic system, and through them pass the receptor and pre-ganglionic effector neurons of that system. Unfortunately, the exact path pursued by these neurons from, and to, viscera is not thoroughly established, so that what follows may not be correct.

As regards the *receptor neurons* of the vertebral sympathetic system it appears almost certain that all viscera send in receptor impulses, therefore there must be receptor neurons, the general course of which has been indicated on page 63. Having gained the spinal cord in the manner indicated this receptor neuron establishes synaptic contact, within the lateral grey column of the spinal cord, with the dendrons of a pre-ganglionic effector neuron.

The *effector response* to the entero-ceptive stimulus conveyed centrally in the manner hypothesized traverses two series of neurons, pre-ganglionic and post-ganglionic. The *pre-ganglionic effector neuron* has its cell-body in the lateral column of the grey matter of the spinal cord. Its axon passes thence through the ventral root of the spinal nerve of the segment concerned, and on through a white ramus communicans to the vertebral sympathetic trunk. It ends either in the corresponding lateral ganglion, or runs on into one of the collateral ganglia, or even into one of the terminal ganglia, by arborising around the second or post-ganglionic neuron. The *post-ganglionic effector neuron* has its cell-body situated in one or other of the ganglia mentioned and its axon runs thence to its appropriate destination, namely, along blood-vessels to deep parts, and along spinal nerves, which it reaches by the grey rami communicantes, to more superficial parts.

Such a type of simple neuronic reflex arc—one receptor neuron and two effectors, pre- and post-ganglionic—appears

to be admirably adapted (a) for the rapid transmission of receptor impulses, as such impulses traverse one neuron only and react at once on the pre-ganglionic effector neuron; and (b) for a wide radiation of effector impulses, as such impulses traverse a synapse with possibilities of branching discharge, and may be transferred to one or more post-ganglionic effector neurons, which run straight to their destinations. This type of neuronic reflex arc seems to be moderately typical of the vertebral sympathetic system, though it is not to be supposed that all visceral arcs are of this simple form. It is not improbable that some of the ingoing receptor neurons from viscera may ascend in the vertebral sympathetic chain, and give off collaterals which enter two or more segments of the spinal cord, in which case a still larger number of effector neurons will be stimulated.

Local Visceral Reflexes. If all the nerves leading to or from viscera be divided there still occur in the gut wall certain purely local reactions, which clearly do not involve neuronic arcs passing through the spinal cord, but must be mediated by cells or simple nerve tissue in the gut wall itself. Reflexes of this character are known as *myenteric reflexes* to differentiate them from those autonomic actions effected by the neuronic arcs described.

Summary of Visceral Reflexes. There appear to be two visceral reflex arcs, the one mediated in the gut-wall itself, and the other involving the spinal cord, and thus Cajal's first two epochs of neuronic arcs (see page 7) are here represented in man.

The *epoch of irritability* by the myenteric reflexes.

The *epoch of the reflex arc* through the single receptor neuron, directly stimulating the pre-ganglionic effector neuron, which establishes contact with one or more post-ganglionic effector neurons, and thus transfers a receptor impulse from a localised spot to an extensive area of reaction.

"Under normal conditions we are not clearly conscious of our internal organs, whereas the specific sensations aroused by the action of the outer world on the afferent nerves 'of

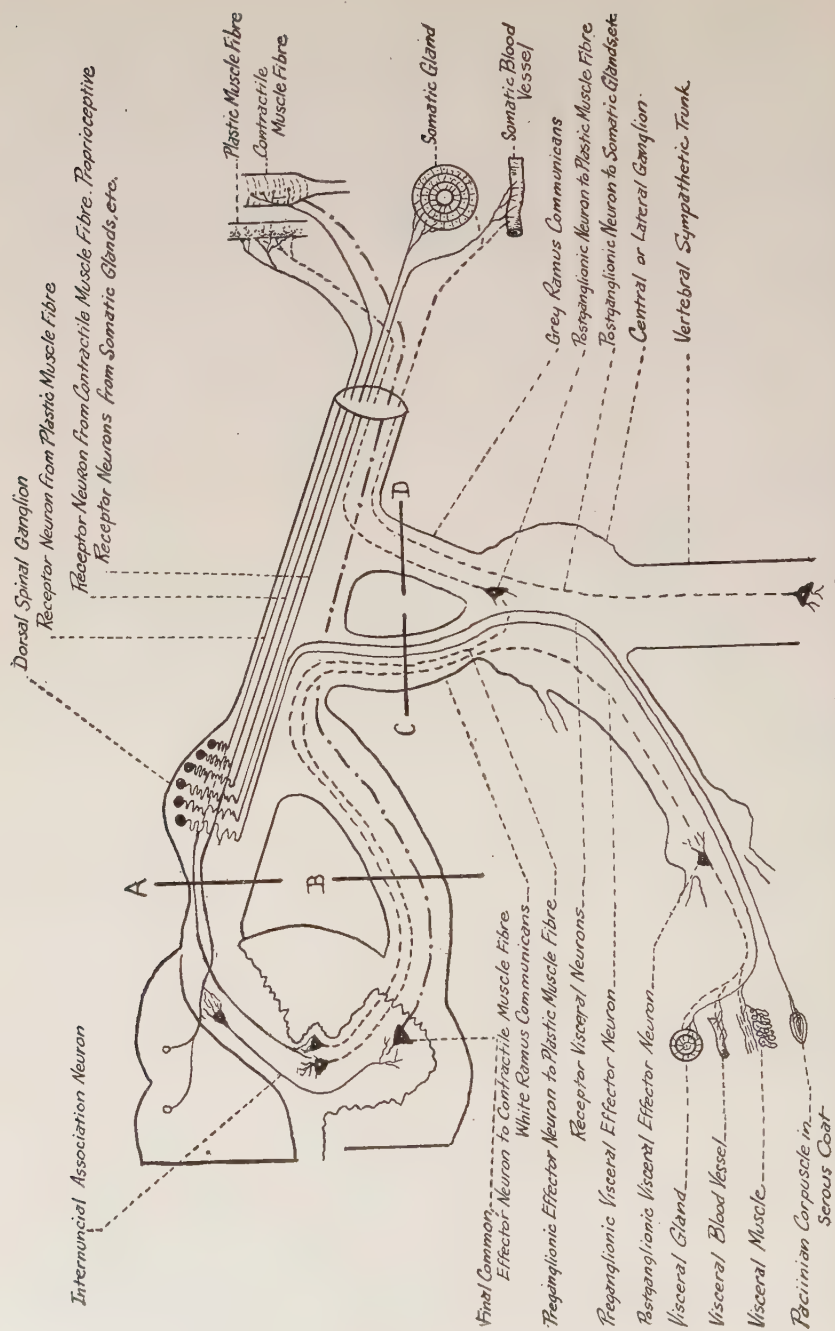


Fig. 23.—Scheme of the chief structural elements and connections of the rami communicantes. See pages 31, 62, 97, 123.

SCHEME OF THE CHIEF STRUCTURAL ELEMENTS AND COMMUNICATIONS OF THE RAMI COMMUNICANTES

WHITE RAMI COMMUNICANTES consist chiefly of:

- a. Visceral receptor neurons which form the great majority of ascending axons of the vertebral sympathetic trunk.
- b. Pre-ganglionic visceral effector neurons which form the great majority of the descending axons of the vertebral sympathetic trunk.
- c. A white ramus contains both receptor and effector autonomic neurons of segments other than its own.

GREY RAMI COMMUNICANTES consist chiefly of:

- a. Post-ganglionic effector neurons passing into the spinal nerves and distributed thence as vasomotor, secretory, and pilomotor axons to somatic blood-vessels, glands and smooth muscle of hair follicles.
- b. Post-ganglionic effector neurons to somatic plastic voluntary muscle fibres.
- c. Receptor fibres?

Section of the dorsal spinal nerve root at *A* cuts off all the incoming somatic and autonomic receptor impulses, proprio-ceptive, extero-ceptive and entero-ceptive.

Section of the ventral spinal nerve root at *B* cuts off the final common effector neurons (lower motor neurons) to somatic voluntary muscle and all pre-ganglionic autonomic effector fibres to viscera and somatic plastic muscle.

Section of the white ramus communicans at *C* cuts off all receptor and effector stimuli from and to the viscera, not necessarily of the arc concerned but to some visceral structures controlled by the vertebral sympathetic trunk or its ganglia.

Section of the grey ramus at *D*,—*lumbar ramisection*. Autonomic innervation of the muscles in the area of distribution, as well as of the blood-vessels and sweat-glands is destroyed, but the vertebral sympathetic ganglia and the visceral nerves are left undisturbed and the patient is spared the effects of loss of control of visceral function.

our skin and special sense organs,' that is, extero-ceptor impulses through receptor nerves, are the source from which our consciousness is developed. But, although secretory processes and the movements of the gut do not usually pass the threshold of consciousness, our internal sensations send impressions to the brain which affect and colour our individuality, and we become aware of any great change in them. Hence they may play a part in producing melancholia and hypochondriasis on the negative side, or a sense of well-being on the positive side. . . . Usually if our internal sensations are intense enough to affect consciousness they excite pain. . . . Any sensation, whether of internal or external origin if it becomes sufficiently intense, becomes painful." (Langdon Brown.)

The Parasympathetic System. Notwithstanding that the parasympathetic portion of the autonomic nervous system cannot be seen with the naked eye, it is impossible to understand the physiological and clinical significance of this important, but insufficiently known system without extended reference thereto.

Whilst the parasympathetic system would appear to be mainly effector in function, it can hardly be doubted that both the bulbar and sacral autonomies receive receptor impulses from all the organs to which they send effector neurons, though this conception of the system is not universally accepted; indeed, some authorities regard the parasympathetic as being effector only. As regard the effector neurons of the parasympathetic system, they conform to the same general laws as govern those of the vertebral sympathetic system, that is, they comprise at least two series of neurons, but tend to have the cell stations of the second or post-ganglionic effector neurons nearer the structure to be affected. In this way the effector results of parasympathetic innervation are more localised and less widely spread than are those of vertebral sympathetic innervation.

Like the vertebral sympathetic, the parasympathetic system controls functions of organic life, acts independently of

the will, and performs many reflex activities which are essential to the maintenance and preservation of life.

Subdivisions of the Parasympathetic System. As has already been stated, the parasympathetic system does not form a visible anatomical chain, like the vertebral sympathetic, but consists of microscopic neurons, with ganglia placed more peripherally. Its pre-ganglionic effector neurons leave the central nervous system at opposite ends as follows:

Cranial outflow.

From the midbrain—midbrain or tectal autonomics.

From the medulla oblongata—bulbar autonomics.

Sacral outflow.

From the sacral region of the spinal cord—sacral autonomics.

The *cranial outflow* is mainly concerned with functions necessary for bodily conservation, whilst the *sacral outflow* chiefly governs the emptying of viscera. "Like the cranial division, the sacral is engaged in internal service to the body, in the performance of acts leading immediately to greater comfort." (Cannon.)

The Midbrain or Tectal Autonomics. Fibres from the midbrain emerge in the oculomotor nerve, and pass, *via* the ciliary ganglion, to their destination. The pre-ganglionic effector neurons end in the ciliary ganglion. The post-ganglionic effector neurons arise in that ganglion, pass out as the short ciliary nerves, and innervate the plain muscle of the iris (sphincter of the pupil) and the ciliary muscle.

The Bulbar Autonomics. The pre-ganglionic neurons of this system run chiefly in the facial, glossopharyngeal, vagus, and possibly the accessory nerves. Those which run in the facial and glossopharyngeal nerves probably supply the glands and blood-vessels (vaso-dilator fibres) of the mucous membrane of the nose and mouth, whilst some of them also reach the trigeminal nerve by way of anastomosing branches, and are distributed with it. They terminate mainly in the spheno-palatine (Meckel's), otic, submaxillary, and sublingual ganglia. The post-ganglionic neurons arise in these ganglia and pass peripherally therefrom to their destinations. In

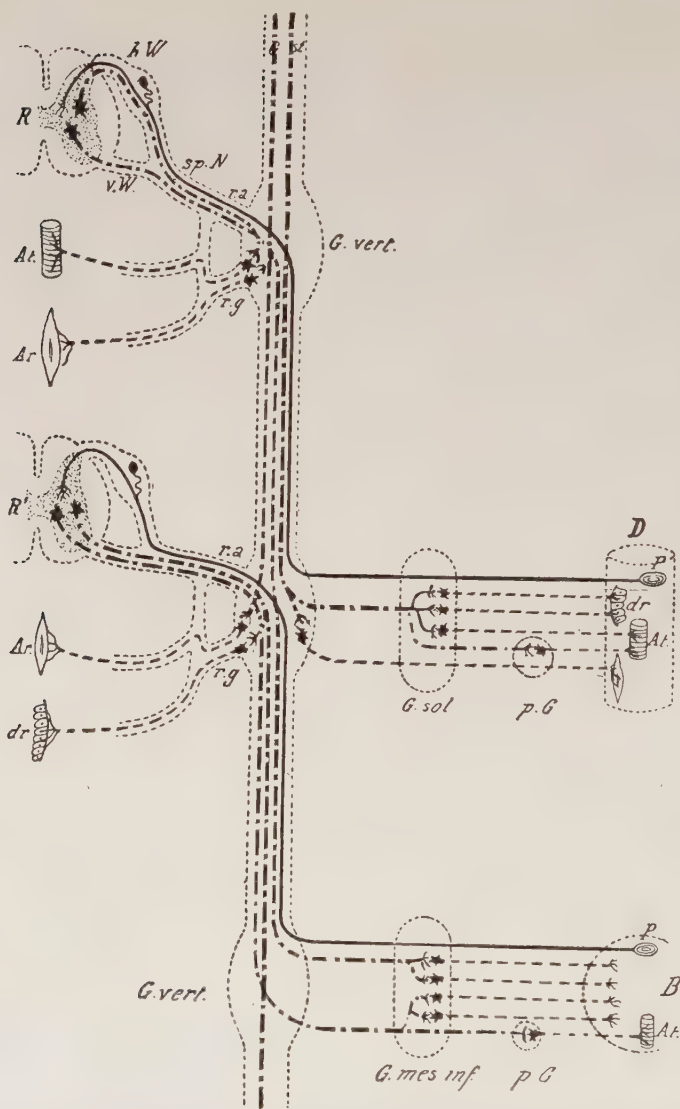


FIG. 24.—Diagram of the nervous elements which make up the autonomic, sympathetic or splanchnic system. (Baglioni.) *R, R*, spinal cord; *h.W.*, dorsal root; *v.W.*, ventral root; *sp.N.*, spinal nerve; *r.a.*, white ramus communicans; *r.g.*, grey ramus communicans; *G.st.*, lateral chain; *G.vert.*, ganglia of lateral chain (vertebral ganglia); *G.sol.*, solar ganglion; *p.G.*, peripheral ganglia (terminal); *G.mes.inf.*, inferior mesenteric ganglion; *D*, intestine; *B*, bladder. The left side of the figure shows the peripheral cutaneous system (*Ar.*, arterial walls; *dr.*, gland cells); the right gives the peripheral splanchnic system (*At.*, arterial walls; *dr.*, gland cells); *P*, Pacinian corpuscles). The receptor paths and cells are black; the effector preganglionic (intra-central), by heavy lines of dots and dashes; the effector post-ganglionic paths and cells, by heavy lines of dashes alone. (From: Luciani, "Human Physiology.")

visceral stimulation should be confined to the segments of the spinal cord concerned, but as there is a spinal cord synapse between the receptor neuron and outgoing pre-ganglionic effector neuron, there is a possibility of branching discharge, and the overflow may reach other neurons and so produce an effector response of a reflex character in other parts of the body, as for example, when a diseased viscus is attended by rigidity of voluntary muscle over the inflamed part. Here the visceral receptor impulse has clearly overflowed, at the synapse, into a somatic arc. Carried to a still greater extent this visceral abnormal overflow may reach the thalamus and cortex and so give rise to sensations of pain. The synapses also afford a possibility of nerve impulses from other sources gaining access to the visceral neuronic arc and so producing aberrant effector visceral responses.

These general facts relative to visceral innervation are of very great clinical importance. Under normal conditions visceral entero-ceptive stimuli do not reach consciousness, so that in health we are unaware of the functional activity of the viscera. When we become aware that we possess such bodily organs it is a sure sign that something is wrong. In certain conditions of health, as also in most diseased conditions, these visceral entero-ceptive impulses may become so intense, even from summation of stimuli, as to give rise to conscious sensation. Such visceral sensations may be generalised or localised. *Generalised*, as in the nausea of gastro-intestinal irritation, or the air-hunger of respiratory obstruction. *Localised*, as in the referred pains of visceral disease, where the pain is referred by the patient to the area of skin corresponding to the nerve root which conducts the receptor impulses. As examples, may be mentioned referred pain along the inner border of the left arm in angina pectoris, hyperæsthesia of the left upper abdomen in gastric ulcer, and pain in the testis, with hyperæsthesia of the scrotum, in renal calculus.

As examples of the double effector autonomic innervation of viscera, mutually antagonistic, may be mentioned the following:

The *heart* receives parasympathetic or inhibitory impulses through the vagus, and vertebral sympathetic or accelerator through, probably, the inferior cervical ganglion.

The *intestine* receives parasympathetic or effector impulses through the vagus, and vertebral sympathetic or inhibitory through the splanchnic nerves.

The *pupil* is contracted through the parasympathetic system by way of the midbrain autonomics, the oculomotor nerve, ciliary ganglion, and short ciliary nerves, and dilated through the vertebral sympathetic by way of the medulla, spinal cord, upper thoracic nerves, cervical sympathetic, cavernous plexus, ophthalmic division of the trigeminal nerve, and the long ciliary nerves.

At the *lower end of the intestine*, that is, the parts developed from the hind-gut, the parasympathetic vagal fibres are replaced by those branches of the parasympathetic nervous system which emerge by way of the second to the fourth sacral nerves and pass thence direct to the pelvic plexus. The genital organs receive their parasympathetic or vaso-dilator fibres through these branches, and their vertebral sympathetic or vaso-constrictor fibres through the hypogastric plexus.

Clinical Differences Between the Parasympathetic and Vertebral Sympathetic Systems. The *vertebral sympathetic system* is constantly and normally stimulated by adrenalin, secreted by the medullary portion of the suprarenal gland. The *parasympathetic system* is also probably, and similarly, stimulated by some substance as yet unknown. In this way a certain tone of, or balance between, the two opposing systems is established and maintained. Should this balance between the two be disturbed, then, as already stated, symptoms of functional disorder or disease are quickly produced. An excessive tone of the parasympathetic system is spoken of as *vagotonus*, whilst a similar condition of the vertebral sympathetic is known as *sympatheticotonus*. All human individuals are said to belong to one or other of these two types, according as to whether parasympathetic or vertebral sympathetic activity prevails.

The *vagotonic* or *parasympathetic type* is reserved and cold-blooded, with slow pulse, contracted pupil, deep-set eyes, and cool pale skin, which perspires easily, even sometimes in patches. Such individuals also show, not infrequently, other clinical evidences of excessive vagal activity in the form of gastric hyperacidity, bradycardia, mild respiratory arrhythmia, and sluggish bowel action. They are also hypersensitive to vagal stimulation by vagotrophic substances like pilocarpin, and to vagal depressors like atropin. It is also not improbable that the symptoms of seasickness are sometimes vago-tonic in origin, and if so, might be benefited by the hypodermic administration of atropin. In this connection, however, the possible influence of the vestibular nerves of equilibration, and their extensive central connections, should not be forgotten.

The *sympathetico-tonic* or *vertebral sympathetic type*, on the other hand, is lively and excitable, with rapid heart, bright eyes, dilated pupils, rosy colour, and a warm, dry skin. This type is specially sensitive to adrenalin. (Eppinger and Hess).

Cervical Portion of the Vertebral Sympathetic System. On account apparently of the fact that the greater part of the cervical portion of the spinal cord is devoted to the points of emergence of the important peripheral nerves of the superior extremity, the course pursued by the pre-ganglionic effector neurons of the cervical portion of the vertebral sympathetic system is both peculiar and important.

The pre-ganglionic effector neurons of the vertebral sympathetic for the head and neck are thrown into it from the spinal cord, through the white rami communicantes from the upper thoracic spinal nerves, and effect synaptic contact with the post-ganglionic neurons in one or other of the three cervical ganglia found on the cervical portion of the vertebral sympathetic trunk. This portion of the trunk supplies oculopupillary fibres to the dilator muscle of the pupil, the non-striated part of the levator palpebrae superioris muscle, and the orbital muscle or muscle of Müller; secretory fibres to the sweat glands of the head and neck and the submaxillary

salivary gland; vaso-motor fibres to the vessels of the head, neck, and arms; pilo-motor fibres to the hair of the head and neck, and accelerator fibres to the heart.

The oculo-pupillary or pupil dilating fibres have a most peculiar and important course. They arise, most probably, from cells in the mid-brain, whence the axons pass down the spinal cord to terminate in the lower cervical region in what has been named the *lower cilio-spinal centre of Budge*. From this point the path is apparently continued by neurons which leave the spinal cord in the vicinity of C8, T1, and T2, and pass thence, *via* the corresponding white rami communicantes,

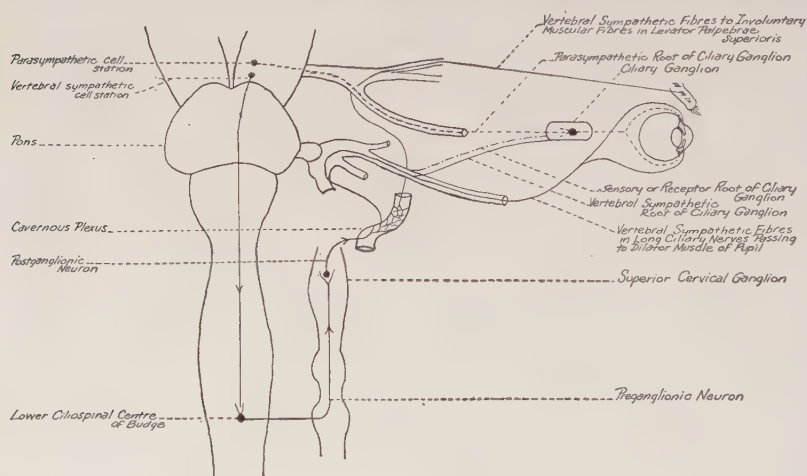


FIG. 25.—Diagram of the probable course of the oculo-pupillary or pupil dilating fibres. See page 94.

into the vertebral sympathetic trunk at the level of the first thoracic ganglion, and thence upwards to the superior cervical ganglion. From this ganglion the path is continued by post-ganglionic vertebral sympathetic neurons to the semilunar (Gasserian) ganglion, by way of the cavernous plexus. They pass thence to their destination by way of the ophthalmic division of the trigeminal nerve and its long ciliary branches. Under normal conditions these neurons are, apparently, in constant tonic activity, so that if the path be interrupted at

any point, the pupil immediately contracts, and the long and complicated anatomical path renders such lesions of not uncommon occurrence.

Lesions of the Cervical Portion of the Vertebral Sympathetic Trunk. In view of the complexity of the pathways through this portion of the vertebral sympathetic system and an insufficient knowledge of the exact course pursued it is not possible to give an adequate picture of clinical lesions of this important part of the system. *Paralysis* may result from gun-shot wounds, stabs, enlarged glands, tumours, injuries, and even from operative interference. Amongst the phenomena that may be noted after such paralysis are slight ptosis from paralysis of Müller's muscle, well contracted pupil from the unopposed action of the parasympathetic, retraction of the eyeball or enophthalmos, diminished intra-ocular tension, vaso-motor disturbances with local flushings, anidrosis, and the like. Conversely, a typical clinical picture of *stimulation* of the cervical vertebral sympathetic trunk will show the reverse phenomena, such as, dilatation of the pupils, exophthalmos, increased intra-ocular tension, vaso-constriction and so forth.

Macroscopic Anatomy of the Autonomic Nervous System.

It is clear that from the clinical standpoint the naked eye anatomy of the autonomic nervous system is of trivial importance as compared with its minute structure and function, the difficulty being that, at the moment, the minute ramifications of the autonomic neurons are not sufficiently worked out. It is further obvious that only certain limited portions of the autonomic nervous system can be seen and studied on the cadaver, these being the gangliated cords of the vertebral sympathetic trunks, with their lateral ganglia and rami communicantes; the branches from these trunks, such as the splanchnic nerves, and the larger and grosser parts of the three præ-vertebral plexuses and their collateral ganglia. Surgical interference is practically limited to division of the vertebral sympathetic trunks or the rami communicantes, and as these almost certainly contain both receptor and effector neurons it

is clear that it is not always certain that the results obtainable are really warranted.

Visceral Pain. As regards visceral pain it is to be noted that under normal conditions there should be no sensations of pain from any bodily viscus. So long as these viscera are in health the individual should be unconscious of their existence, the neuronie mechanism concerned should work automatically and unconsciously, and the nerve impulses should traverse the normal autonomic arcs. If, however, as the result of disease, the autonomic receptor neurons are over, or aberrantly, stimulated the whole condition of things is altered and the occurrence of pain warns the individual that something is wrong. Visceral pain is, therefore, in quite a different category from cutaneous pain. The latter is protective to the individual and is a physiological "sense." The former is also protective but is pathological, that is, visceral pain should never occur in health. It consequently follows that the neuronie mechanism concerned is different.

It is impossible to believe that the human viscera are provided with special pain receptor organs and special pain conductors—for the former would necessitate the latter—and indeed there is no evidence of either the one or the other. If, therefore, there are no visceral pain receptor organs, no visceral pain neuronie arcs, and no special visceral pain tracts, then the manifestations of visceral pain can only accrue from abnormal stimuli producing an overflow of nerve impulse from normal arcs to other arcs. There can be no toothache until the tooth axons are exposed by caries, when they immediately become subjected to a number of aberrant stimuli of a chemical nature, with the result that the nerve impulse now overflows into other and improper neuronie arcs, and so rises to consciousness.

Under normal conditions visceral receptor impulses should be confined to their own segmental neuronie arcs. When these impulses are of an aberrant character, the nerve impulse may overflow at the spinal cord synapse between the receptor neuron and the pre-ganglionic effector neuron into other arcs

—either autonomic or somatic—and thus gives rise to a sensori-motor reflex, as is seen clinically, for example, in the automatic contraction of an abdominal muscle over an inflamed appendix. The nerve mechanism here involved is protective to the organism and is Nature's method of securing rest of an inflamed part. This "overflow" principle has been recognised by MacKenzie as the basic principle of many abnormal clinical reflexes. With a further increase in the intensity of the stimulus, or by a summation of aberrant stimuli, there may be a still greater overflow of nerve impulses to still higher levels of the neuraxis, so that eventually the thalamus may be reached and later the cerebral cortex, with the production of a sensation of pain and a consciousness of its seat. If this be still further prolonged the cortical neurons themselves may give before the strain, hence the mental depression and general intellectual disturbance which may accompany prolonged visceral disease.

That visceral pain is not localised very accurately is probably due to the fact that viscera generally are not very plentifully supplied with receptor autonomic neurons. That visceral pain is so frequently referred to the skin—the viscerosensory reflex—is again almost certainly due to the synaptic connections established in the spinal cord between the autonomic and somatic systems, with the numerous possibilities of branching nerve discharge and the stimulation of other neurons.

Summary of Visceral Sensation. As regards *general visceral sensation*, it seems permissible, in the absence of any evidence to the contrary, to sum up the nerve factors concerned as follows:

There are no highly specialised visceral receptor organs. The visceral stimulus appears to be transmitted direct to the naked axis cylinder process, or through an epithelial cell, or, as in the case of a serous coat, through a Pacinian corpuscle.

Both the tunica mucosa and the muscular coat of a viscus appear to be capable of transmitting receptor impulses centrally, for it is essential that both should work in harmony.

If these harmonious inter-relations be disturbed there will be manifestations of ill-health.

The visceral neuronic arcs concerned are those of the autonomic nervous system, and although not always described, it appears to be necessary to assume that all viscera are provided with receptor neurons. The effector sides of the visceral arcs are provided with more neurons than the receptor, and come under the control of two opposing and antagonistic nerve elements—the vertebral sympathetic and parasympathetic.

The general visceral impulses appear to be aroused by chemical, physical, and mechanical stimuli. Chemical, as in the stomach, physical (temperature) as in the pharynx and upper part of the œsophagus in the swallowing of hot fluids, and mechanical, as in distension or tension of the bladder.

Viscera are constantly transmitting impulses (enteroceptive) centrally. Under ordinary conditions the impulses so conveyed centrally pass over, through the spinal cord, into the effector limbs of the arcs concerned and so produce the necessary reactions of the viscera to the stimuli. As such impulses have not passed to higher levels than the spinal cord segments normally concerned the reactions occur automatically and do not arouse consciousness.

On account of the numerous spinal cord synapses between the visceral autonomic neurons and those of the central nervous system and the possibilities thereby presented of branching discharge, there is an effective neuronic machinery provided for visceral impulses, especially those of an aberrant nature, to reach the brain and so produce consciousness. This may occur normally as the result of a summation of stimuli, as in the gradually distending genital organs arousing sexual desire, or abnormally, as the result of too powerful or aberrant stimuli and the consequent overflow of the nerve impulse to somatic arcs. Visceral pain does not, therefore result from the stimulation of special pain receptors with special cortical pain centres, but from aberrant visceral impulses overflowing into unusual neuronic arcs, so gradually reaching the brain and arousing there a visceral consciousness.

The whole nerve mechanism concerned in visceral innervation is protective to the organism and is an example of Nature's attempt to effect a cure by rest of the affected part.

Clinically, if the cause of the aberrant stimulus to the receptor visceral neurons can be diagnosed and removed, a cure will be effected.

CHAPTER VII

THE PROPRIO-CEPTIVE IMPULSES AND PATHWAYS

Definition. By the proprio-ceptive impulses are meant those somewhat vaguely perceived impulses which are transmitted centrally from the skeletal muscles, tendons, joints, and semi-circular canals, and have, as their great function, the balancing of the body in space and its consequent adaptation to its environment. The absolute necessity for such regulation is well seen in the ataxic gait of a patient suffering from locomotor ataxia in whom these proprio-ceptive impulses from muscles, tendons, and joints are more or less completely lost on account of the destruction of the neurons concerned.

The Receptor Organs of the Proprio-ceptive System. The receptor organs of the proprio-ceptive system are contained within the skeletal muscles, joints, tendons, and semi-circular canals. They are stimulated by the normal functioning of these structures, and thus report to the central nervous system the exact state of contraction of the muscle, flexion of the joint, tension of the tendon, and so on. The reactions to these stimuli are generally performed unconsciously, and it is not improbable that cutaneous sensibility may also participate therein.

The *receptor organs of voluntary muscle* are known as muscle spindles, and are stimulated by the contraction of the muscle. These muscle spindles are connected to the peripheral processes of bi-polar receptor neurons. When the former are stimulated the latter are aroused to discharge nerve impulses, and so the proprio-ceptive sensation from voluntary muscle is conveyed centrally, and the innervation is cerebro-spinal. It is not improbable, that voluntary muscles also discharge receptor impulses into the autonomic nervous system, in which case the former innervation is con-

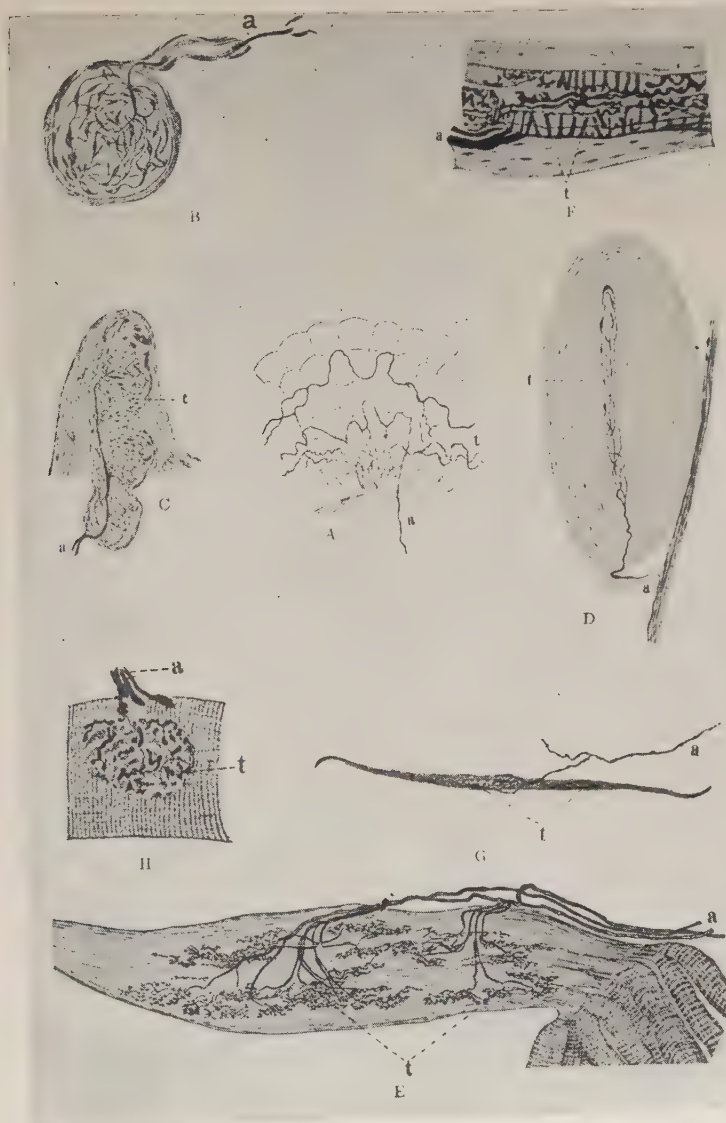


FIG. 26.—Some examples of receptor organs. A. "Free termination" in epithelium (after Retzius). B. Krause's corpuscle from conjunctiva (after Dogiel). C. Meissner's corpuscle from skin (after Dogiel). D. Pacinian corpuscle (after Dogiel). E. Termination upon tendon sheath (Huber and DeWitt). F. Neuromuscular spindle (after Ruffini). G. Motor termination upon smooth muscle-fiber. H. Motor "end-plate" on skeletal muscle fiber (after Böhm and von Davidoff). a, axone; t, telodendria. (From: Morris, "Human Anatomy.")

cerned with the contractile tone of the muscle, and the latter with postural tone. In the case of the receptor impulses responsible for the maintenance of postural tone, the receptor organs appear to be the naked extremities of bi-polar receptor autonomic axons themselves.

Quite apart from the reactions produced in voluntary muscles as the result of these proprio-ceptive impulses, such muscles may also react to extero-ceptive impulses, and are thus voluntarily excited to action.

As regards the *unstriated and involuntary musculature of viscera*, the stimuli belong to the entero-ceptive system, not the proprio-ceptive, and hence the contractions which result are usually involuntary and unconscious, and the innervation concerned is purely autonomic.

The chief *receptor organs of tendons* are probably the corpuscles of Golgi. These are stimulated by the stretching of the tendon during muscular contraction.

The *receptor organs of joints* are probably the corpuscles of Pacini, which are stimulated by the movements or bending of the joint, and the central nervous system is thus informed of the degree of flexion, or otherwise, of the joint.

The *receptor organs of the static and equilibratory apparatus*—the most important of the proprio-ceptive senses—are probably the hair cells which project into the endolymph of the ampullæ of the semi-circular canals, and are surrounded by arborisations of the receptor neurons of the vestibular nerve of equilibration. Movements of the head cause currents of endolymph to impinge upon these hair cells, thus stimulating the vestibular nerve.

This static and equilibratory proprio-ceptive sense is the most important of such senses, and acts in conjunction with all the other somatic senses in the maintenance of equilibrium, posture, and tone of the muscular system generally. The eyes, and most of the other extero-ceptive sense organs, so far as they act in the manner just described, also serve as adjuncts to this proprio-ceptive system.

Proprio-ceptive Neurons. Proprio-ceptive neurons thus

respond to stimuli arising within the body itself. They convey impulses aroused by muscles, tendons, joints, and the semi-circular canals, and for such impulses the cerebellum is the great correlation centre. Of the long ascending tracts which some of these proprio-ceptive neurons form in their upward passage through the white matter of the spinal cord, all pass to the cerebellum. The gracile and cuneate tracts not only transmit such impulses to the cerebellum, through the external arcuate fibres, but are also connected, by a second series of neurons with the thalamus, and thence on to the cortex by a third series of neurons. In this way may be aroused those vague subconscious sensations of posture and spacial adjustment which are characteristic of proprio-ceptive sensations. But the cerebellum itself is also connected to the cerebral cortex, so that all proprio-ceptive impulses must sooner or later exert an influence on the brain.

As these proprio-ceptive impulses, like entero-ceptive impulses, are continually being transmitted centrally, eventually reaching the brain, it follows that they are perpetually exercising an influence on the cortical neuronie pattern, and play, therefore, a part in the moulding of the mind. The truth of this is, perhaps, best seen in certain pathological conditions, where, as the result of long-standing disease of muscles, joints, tendons, or equilibration, the patient's mental outlook may become altered and depressed.

Tracts of the Spinal Cord. When it is said that certain axons, or groups of axons, with a known specific function, form "tracts" in the spinal cord, it is not to be assumed that such tracts can be seen with the naked eye. The white matter of the spinal cord, composed, as it is, of medullated axons, is perfectly homogeneous in appearance. It is, however, known, as a result of an attentive study of disease and of much experimental and histological research, that specific functional groups of axons entering the white matter of the spinal cord through the dorsal roots of the spinal nerves occupy quite distinct and definite positions within that white matter, and such areas are known as "tracts." It is of fundamental importance

in both Neurology and disease that these tracts should be attentively studied.

Tracts of the Proprio-ceptive System. The tracts of the proprio-ceptive system all pass upwards through the spinal cord, *except* those from the semi-circular canals, which enter the cerebro-spinal axis at a higher level and do not, therefore, fall to be considered until a later stage. (See page 207.) The proprio-ceptive tracts may be generally set forth as follows:

Proprio-ceptor tracts passing to the cerebellum.

1. The direct or dorsal spino-cerebellar tract of Flechsig.
2. The indirect or ventral spino-cerebellar tract of Gowers.
The external arcuate fibres convey impulses to the cerebellum from the gracile and cuneate tracts of Goll and Burdach.
3. The vestibular nerve, the nerve of equilibration, from the semi-circular canals.

Proprio-ceptive tracts passing to the brain stem.

Certain fibres from the indirect or ventral spino-cerebellar tract of Gowers.

Proprio-ceptive tracts passing to the gracile and cuneate nuclei (Medulla oblongata), thalamus, and cerebral cortex, thus arousing vague subconscious sensations of posture and spacial judgment.

4. The gracile tract of Goll.
5. The cuneate tract of Burdach.

The general pathway pursued by neurons of this order is from the receptor organs along the peripheral nerves, thence into the spinal cord by the dorsal roots of the spinal nerves, and up to their several destinations by the tracts mentioned above. The cell stations for all the primary receptor neurons of the series are in the ganglia of the dorsal roots of the spinal nerves.

The Direct or Dorsal, and the Indirect or Ventral, Spino-Cerebellar Tracts of Flechsig and Gowers. The axons which form these tracts belong to the *second* series of neurons over which proprio-ceptive impulses, concerned in the maintenance of equilibrium, from the muscles, tendons, and joints of one side of the body are conveyed to the cerebellum of the same side, the connection being thus an ipsilateral one. The *first*

series of neurons have their nerve cells in the spinal ganglia of the dorsal spinal nerve roots, the peripheral portions of their axons in the peripheral nerves, whilst the central portions of these axons enter the spinal cord in the dorsal roots of the spinal nerves, and terminate in arborisations around the cells of the dorsal nucleus of Clarke.

The *second* series of neurons over which the impulses are conducted constitute the tracts themselves. Those which form the direct or dorsal spino-cerebellar tract of Flechsig arise from the cells of Clarke's nucleus of the same side. The axons of the indirect or ventral spino-cerebellar tract of Gowers arise from cells scattered through the grey matter, chiefly in the dorsal grey column of the same side, though some are derived from cells on the opposite side.

From these cell stations arise axons, some of which traverse the cord to take up a position on the periphery of the lateral white funiculus immediately ventral to the entering dorsal nerve roots, and, turning upwards (cerebrally), form the *direct* or *dorsal spino-cerebellar tract of Flechsig*. These fibres enter the cerebellum directly by passing through the restiform body (inferior cerebellar peduncle); others of these proprio-ceptive axons take up a position on the periphery of the lateral white funiculus immediately dorsal to the emerging ventral spinal nerve roots, and turning upwards (cerebrally), form the *indirect* or *ventral spino-cerebellar tract of Gowers*. Traversing the spinal cord, medulla, and pons, these fibres enter the cerebellum indirectly by passing through the superior cerebellar peduncle (brachium conjunctivum). The axons of both tracts terminate in arborisations around cells of the cerebellar cortex, particularly those of the superior vermis. Some of the axons of Gowers' tract, instead of passing to the cerebellum, are continued through the pons and mid-brain, to end partly in the corpora quadrigemina, and partly in the thalamus of the same side, and are hence occasionally termed the *spino-tectal* and *spino-thalamic tracts*.

The *vestibular nerve*, the nerve of equilibration, from the semi-circular canals, does not, of course, traverse the spinal

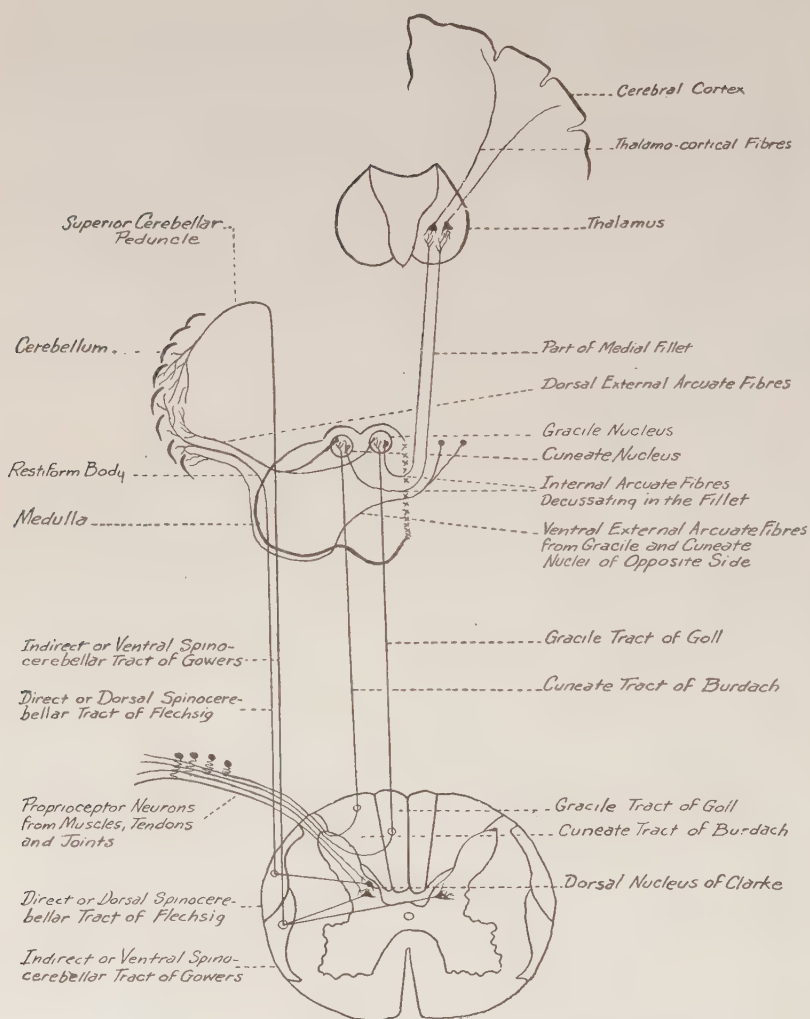


FIG. 27.—Scheme of the proprio-ceptive tracts in the spinal cord.
See pages 102, 179, 181, 183, 184, 282, 308.

cord, and is consequently considered at a later stage. (See page 207.)

The gracile and cuneate tracts of Goll and Burdach. The nerve cells of the axons which form these tracts are situated within the spinal ganglia on the dorsal roots of the spinal nerves. The *peripheral axons* pass from the periphery of the body through the peripheral nerves. The *central axons* run through the dorsal roots of the spinal nerves, and entering the spinal cord, form the greater bulk of the dorsal white funiculus. Those axons which first enter the cord occupy the medial position; those which enter at higher levels lie on the lateral side. Consequently the fibres from the inferior extremities and lower parts of the trunk which enter through the sacral, lumbar, and lower thoracic dorsal nerve roots are found on the medial side of the funiculus, and form the *gracile tract of Goll*. Those from higher levels than the fifth thoracic similarly form the *cuneate tract of Burdach*. Running throughout the whole length of the cord, the axons of these tracts terminate in arborisations around the cell bodies of the secondary series of neurons within the gracile and cuneate nuclei in the medulla oblongata, whence the impulses are passed on by two different routes to the cerebellum and brain.

In their path through the spinal cord, these axons, in accordance with the laws governing all tracts within the spinal cord, give off numerous collateral branches to the grey matter of the different levels of the cord particularly so within the lumbar and cervical enlargements. As the axons which form these two tracts arise from cells outside the spinal cord they are collectively known as *exogenous fibres*, to differentiate them from axons arising from nerve cells within the spinal cord, and collectively termed *endogenous fibres*.

The *chief function of the gracile and cuneate tracts* is the conveyance, centrally, of impulses of joint and muscle sense; that is, they convey those proprio-ceptive impulses from voluntary muscles, tendons, and joints, through which is obtained an idea of the position of the limbs and the state of contraction of the muscles. A certain proportion of these impulses reach

the cerebral cortex and arouse states of consciousness which give sensations of position, movement, or resistance, and form the basis of judgments as to these conditions. The sensations so aroused within the brain are necessary for the proper co-ordination of the movements of the muscles. Injury to these tracts, while it does not cause paralysis, is followed by disorderly or ataxic movements, as is typically seen in locomotor ataxia—a disease, one of the sequela of syphilis—which affects these tracts. The gracile and cuneate tracts are definitely known not to transmit impulses of pain or temperature, and if they convey any impulses of touch (cutaneous pressure) are certainly not the only avenues of conduction of such impulses.

Impulses travelling through the gracile and cuneate tracts to the cerebral cortex are conveyed over three series of neurons. Those of the *first* are as just described, and consist of the peripheral nerves, the dorsal receptor roots, and the gracile and cuneate tracts. The *second* series have their cells within the gracile and cuneate nuclei. Their axons emerge and mostly decussate in the medulla (decussation of the fillet) to form the “sensory” fillet, and passing as such through the medulla, pons, and mid-brain, terminate, in the thalamus in arborisations around its cells. In this series may also be included those arcuate fibres which arise in the gracile and cuneate nuclei and pass into the cerebellum. The *third* series of neurons pass from the thalamus, through the thalamo-cortical radiation, to the post-central area of the cortex.

CHAPTER VIII

THE EXTERO-CEPTIVE IMPULSES AND PATHWAYS

Definition. By the extero-ceptive impulses are meant those which are aroused by the phenomena of the physical world around, and outside the body, such as light waves, sound waves, heat waves, and so on. These quite definitely arouse consciousness and typically call forth reactions of the whole body, such as locomotion or voluntary muscular movement, which change the relations of the body to its environment. The cerebral cortex is the great correlation centre for most of the complex impulses of the extero-ceptive system which arouse consciousness, and as most of the neurons of this system cross over to the opposite side it follows that the outer physical world has, for the most part, a crossed representation in the cerebral cortex.

Scope and Limitation of the Human "Senses." It is unfortunate that neither the numbers nor the limitations of the special "senses" of man are sufficiently realised. It is a matter of common belief that man has but five senses—sight, hearing, taste, smell, and touch. As a matter of fact he possesses not fewer than twenty different senses spread over the three great groups of entero-ceptors, proprio-ceptors, and extero-ceptors. The first do not normally arouse consciousness; the second produce those vague subconscious sensations referred to in the last chapter; the last produce consciousness in accordance with the extent of their neuronie construction. Receptor impulses from these three several great sources are continually being poured into the human brain and are the sources of all our mental reactions. In accordance with the continuity of their reception the neuronie pattern of the cerebral cortex is continually being altered.

Although the human special senses are more numerous than commonly supposed, they are limited in their range. Speaking of these limitations Herriek says, "of the complete series of ethereal vibrations, we can only sense directly about one octave by the eye and a number of others through the sense organs for temperature in the skin, while to the lowest and highest members of the series our sense organs are entirely insensitive. The sensitivity of the skin to these vibrations is limited subjectively to a small range of temperature sensations, while the retinal excitations give us subjectively an extensive series of sensations of colour and brightness. The human eye can discriminate from 150 to 230 pure spectral tints, besides various degrees of intensity and purity of tone, making a total of between 500,000 and 600,000 possible discriminations by the visual organs (von Kries).

"Similarly, the chemical senses, taste and smell, reveal to us only a very small number out of the total series of actual excitations to which our sense organs are exposed. Our organs of taste, in fact, can respond to only four types of chemical substances, with only four subjective sense qualities, *viz.*, sour, salty, sweet, bitter. The organs of smell respond to a larger range of chemical stimuli and to far greater dilutions, *i. e.*, the threshold of sensation is far lower for smell than for taste.

"Many of the lower animals have very different limits of susceptibility to the kinds of stimulation which we have just been considering, and in some cases they have sense organs which are attuned to respond to a quite different series of environmental factors than are our own, as, for example, the lateral line sense organs of fishes. We can form no idea how the world appears to such organisms except in so far as their sensory equipment is analogous with our own.

"From these illustrations it is plain that the sensory equipment of the human body is adapted to respond directly to only a limited part of the environing energy complex, the remainder having little, if any, practical significance in the natural environment of primitive man."

Great Importance of the Extero-ceptive Senses. It should thus be clear that extero-ceptive impulses play a very important part in the formation of "mind," that they arouse consciousness, that the reactions to the environment vary with their nature, that they are perpetually altering the neuronie construction of the brain, and that they are not only limited, but that they differ very materially in different individuals, these differences being largely influenced by the varying numbers of neurons for their central transmission, and above all, by the individual possession of an adequate number of cortical neurons for their receipt, storage, and translation.

"The importance of these (extero-ceptive) sensations in our conscious experience is no doubt correlated with the fact that it is through the reactions, called forth by such external stimuli, that the organism is enabled to respond appropriately to the various situations in its constantly changing environment. To meet these complex and variable situations correctly requires the nicest correlation of sensory (receptor) impulses from the various sources as well as their integration with vestiges of past experience, and it is in connection with these higher correlations and adjustments that consciousness appears. The responses initiated by entero-ceptive and proprio-ceptive afferent (receptor) impulses are more stereotyped and invariable in character; and these reactions are for the most part carried out without the individual being aware either of the stimulus or the response. . . . A single object may appeal to many sense organs, and our perception of that object involves a synthesis of a corresponding number of sensations and their comparison with past experience. For example, when I meet a friend and grasp his hand in greeting, my perception of him includes not only the image of his face but also the sound of his voice and the warm contact of his hand. Thus, thermal, tactile, auditory, and visual sensations may be fused in the perception of a single object, and this involves an integration of the corresponding afferent (receptor) impulses within the cerebral cortex. Accordingly,

it becomes of special interest to trace the course of these afferent (receptor) extero-ceptive impulses from the various extero-ceptive sense organs to their cortical receptive centres." (Ranson.)

The Extero-ceptive "Senses" and Their Receptor Organs. The extero-ceptive "senses" comprise those of touch, temperature, pressure, cutaneous pain, general chemical sensibility, hearing, sight, and smell. Taste is, in man, a strictly entero-ceptive sense, whilst smell, which was originally an entero-ceptive sense, has become, with the process of evolution and alteration, an extero-ceptive one, but, in any case, has almost disappeared from the range of human "senses." Of these extero-ceptive senses those for touch, temperature, pressure, and pain, have their receptor organs, if any, situated in the skin; those for general chemical sensibility in moist epithelial surfaces; whilst the highly specialised senses of hearing, sight, and smell have their elaborate receptor organs in the internal ear, the eye, and the nose.

Receptor organs of touch and pressure fall into two groups:

- A. Those for deep sensibility or pressure.
- B. Those for cutaneous sensibility or touch.

As regards *deep sensibility or pressure*, the sense seems to be subserved by all three of the great receptor systems, entero-ceptive, proprio-ceptive, and extero-ceptive, but chiefly through the first two, in which the receptor organs appear to be the naked axons themselves. Extero-ceptive impulses of pressure are probably aroused through the Pacinian corpuscles, through which relatively coarse degrees of pressure may be discriminated and localised. In any case this "sense" appears to be preserved intact after the loss of all cutaneous nerves.

As regards *cutaneous sensibility or touch* there appear to be two groups of receptor organs:

- A. Those arranged in the hair bulbs at the roots of the hairs.
- B. Those on hairless parts such as the lips, palms of the hand, fingers, and soles of the feet. These are the organs of the most refined active touch.

By means of the sense of touch the brain is informed of the shape, texture, hardness, and other qualities of bodies with which the skin is in contact, though such cerebral judgment is probably based on other sensations besides those of touch. Tactile sensibility of the skin, like its temperature sensibility, is due to the presence within it of a number of touch spots or receptor organs. These areas, which are naturally extremely sensitive, are separated by other areas almost or entirely insensitive to touch. These touch spots are arranged chiefly around the hairs, and vary in number in different parts of the body. The receptor organs would here appear to be a sheaf of very sensitive tactile nerve fibres around the follicles of the hairs, whilst Meissner's corpuscles (the corpuscula tactus of Quain's Anatomy) appear to be the type found in the papillae of the skin of the hand and foot and many other parts of the body.

As regards the *sensibility of the skin to temperature*, that is, heat and cold, Herrick is of opinion that the end-bulbs of Krause may be the cold receptors, and the corpuscles of Dogiel may be those for heat, whilst Head thinks that each of these types of sensibility may be present in an epicritic and a protopathic form. The temperature sense, like the touch sense, would appear to be distributed over the skin in the form of warm and cold spots; the latter are apparently more extensively distributed over the body than are those for the appreciation of warmth, and the whole temperature sense of the skin is unequally spread over the body, that is, all parts of the skin are not equally sensitive to differences in temperature, and the sense is even less marked in the mucous membranes, hence it is possible to drink hot fluids at a temperature which would be painful to the hand, and still more to any other part of the body. It has been suggested that the heat receptors are more deeply situated in the integuments than the cold, but in any case histological evidence as to the identity of these receptors is still very uncertain.

That the skin is capable of receiving and transmitting impulses which give rise to a *sensation of pain* is undoubted, and it is clear that, from the standpoint of the self-preserva-

tion of the individual, this pain sense is all important. From the physiological aspect, it is a remarkable fact that pain may result from changes in organs which are devoid of ordinary sensibility, as is particularly well seen in viscera. The ureters, for example, are devoid of sensation, but can give rise to excruciating agony when they are firmly contracted on a retained calculus. As the problem of visceral pain is discussed elsewhere (see page 96), it suffices to say here that, as regards sensations of pain, there are two schools of neurological thought, the one holding that there are special pain receptors with definite pain tracts, and the other affirming that pain is a quality which may be present in any sense, and is not in itself a true sensation, but only a resultant from aberrant stimuli and the overflow of such stimuli to other neurons. The confusion probably arises from an inability to differentiate between physiological cutaneous pain and pathological visceral pain.

Head and his colleagues are of the opinion that all forms of cutaneous sensibility, among which they include touch, temperature, and pain, are grouped in two series, each served by different receptor organs and receptor neurons, and termed by them *protopathic* and *epicritic sensibility*. On the other hand the more recent researches of Carr, Boring, and Stopford do not appear to confirm this, and hence Herrick concludes that this distinction of cutaneous sensibility into *protopathic* and *epicritic* "may hereafter be ignored."

In the widest sense of the word the skin is protective, and is richly endowed with sense organs which bring the organism into relationship with the outside world. Amongst these "senses" of the skin are those of touch, light and deep, including the sense of discrimination, the sense of temperature, and the sense of pain, though it is clear, from what has been stated, that there is even yet an insufficient knowledge as to the mechanism by means of which these cutaneous "senses" are operated.

Receptor organs for general chemical sensibility appear to be restricted, in man, to moist epithelial surfaces, such as the

mouth cavity, though in lower animal forms, such as fishes, such organs may occur all over the body. In man this form of extero-ceptive sense has, consequent on the change of the environing medium, lost much of its significance.

The *receptor organ for hearing* is the extremely complicated spiral organ of Corti in the membranous labyrinth of the internal ear. It responds to stimuli created by air vibrations ranging from 30 to 30,000 per second, and gives rise to two forms of auditory sensations—*noise*, stimulated by sound concussions or irregular mixtures of aerial vibrations, and *tone*, stimulated by sound waves of periodic aerial vibrations. It is a peculiar and significant fact that in apparently no animal form is there any provision for the voluntary cutting off of auditory impressions, as is the case with sight, where the eyelids can be closed at will.

The *receptor organ for vision* is to be found in the rods and cones of the retina, which respond to stimuli created by ethereal vibrations ranging from 400,000 to 800,000 billions per second, and giving rise to two forms of visual sensation, *colour*, stimulated by simple ethereal vibrations, and *brightness*, stimulated by mixed ethereal vibrations.

The *receptor organ for smell* is, in man, in a rudimentary condition, and is of such little importance in the human economy as to make its discussion of no importance.

Tracts of the Extero-ceptive System. From the foregoing remarks it follows that the extero-ceptive senses to be transmitted centrally comprise those of touch, temperature, pressure, and pain from the skin generally; general chemical sensibility from moist epithelial surfaces, of no very great importance in man; hearing, vision, and smell. This last, originally an entero-ceptive sense has become an extero-ceptive one. Taste is, in man, a strictly entero-ceptive sense.

Extero-ceptive impulses of *touch, temperature, and pressure*, from all the skin surface of the body, except the head and neck innervated by the trigeminal nerve, pass through the peripheral nerves, dorsal roots of the spinal nerves, spinothalamic tracts of the cord, to the thalamus, and thence to

the neo-pallium of the cerebral cortex. The similar impulses conveyed by the trigeminal nerve reach the cerebral cortex without, of course, traversing the spinal cord.

The *protective impulses of pain* from the skin may or may not have specific pathways or tracts of their own. The evidence is not conclusive, but is discussed later. (See page 119.)

Extero-ceptive impulses of *general chemical sensibility* are not, in man, of any great importance.

The important extero-ceptive impulses of *hearing* are conveyed over the neurons of the cochlear nerve to the thalamus, and thence on to the temporal acoustic area of the neo-pallium of the cerebral cortex.

The extremely important extero-ceptive impulses of *sight* are conveyed over the neurons of the optic nerve to the thalamus, and thence on to the visual occipital area of the neo-pallium of the cerebral cortex.

The quite unimportant extero-ceptive impulses of *smell* are conveyed over the neurons of the olfactory nerves to the archi-pallium of the cerebral cortex.

From the above it consequently follows that the tracing of extero-ceptive tracts through the spinal cord involves only the ventral and dorsal spino-thalamic tracts.

The Ventral and Dorsal Spino-Thalamic Tracts. The axons which form these tracts comprise the *second* series of neurons over which impulses of heat, cold, diffuse tactile discrimination and pain, are conveyed from the opposite side of the body. The *first* series of neurons which conduct these impulses have their cell bodies in the spinal ganglia, their peripheral axons in the peripheral nerves, and their central axons in the dorsal roots of the spinal nerves through which they enter the spinal cord. Having entered the cord, the central axons of the first series of neurons terminate around cells in the dorsal grey column of the same side.

Those of the *second* series of neurons which go to form the *ventral spino-thalamic tract* have their cell bodies in the dorsal grey column, their axons cross the median plane in the ventral white commissure, and ascend in the ventral funiculus, as the

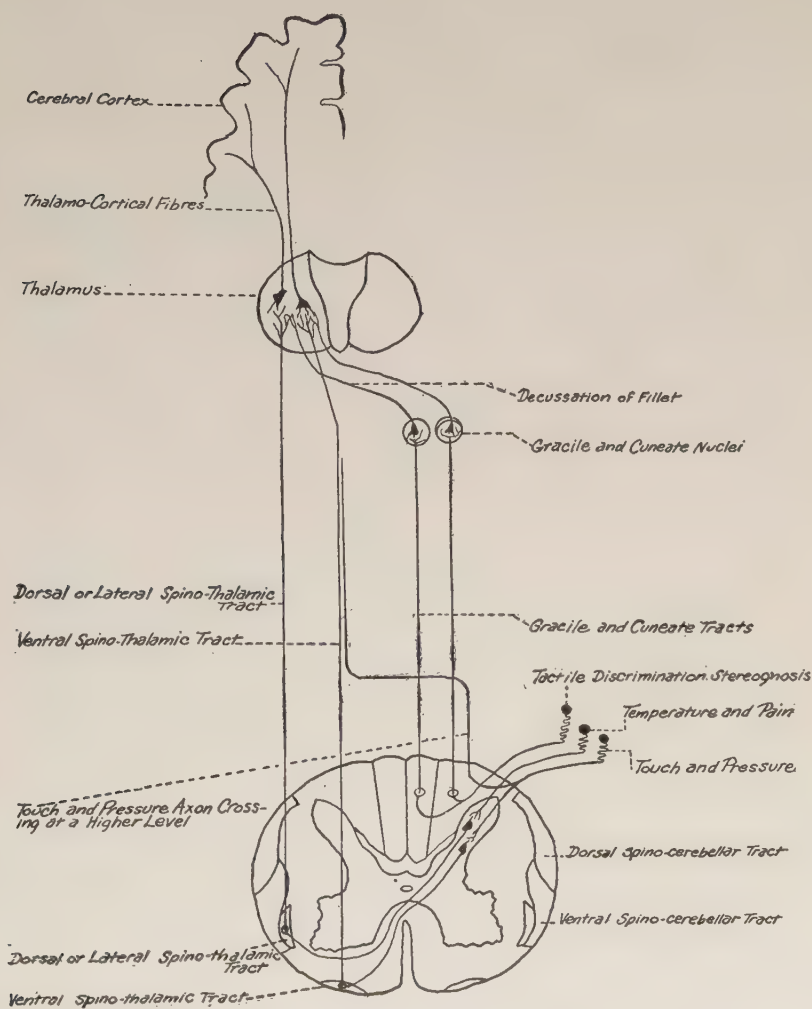


FIG. 28.—Scheme of the extero-ceptive tracts of the spinal cord.
See pages 107, 115, 116, 119.

tract in question, to the thalamus. But the tract contains a number of shorter axons which do not reach the thalamus, but terminate in the grey matter of higher segments of the cord and medulla, so that the pathway consists, in part, of a series of relays of shorter neurons. Assuming that the proprioceptive gracile and cuneate tracts convey also a few exteroceptive impulses of touch (see page 107), then the uncrossed path for such impulses (gracile and cuneate) overlaps, by many segments, the crossed path (spino-thalamics), and this extensive overlapping of the uncrossed by the crossed paths accounts for the fact that lateral hemisection of the human spinal cord rarely causes serious disturbance of tactile sensibility below the lesion.

By means of this tract are conveyed centrally, from the skin, cutaneous impressions of touch, though it is very probable that a smaller proportion of such impulses are also conveyed by the, primarily proprioceptive, gracile and cuneate tracts.

Those of the *second* series of neurons which go to form the *dorsal* (or *lateral*) *spino-thalamic tract* have their cell bodies in the dorsal grey column, their axons cross the median plane in the ventral white commissure and ascend in the lateral funiculus of the spinal cord, as the tract in question to the thalamus. It transmits impulses, from the skin, of temperature and pain. Just as with the ventral spino-thalamic tract, not all the axons of the dorsal spino-thalamic tract reach the thalamus, but terminate in higher segments of the cord. There is thus provided a secondary path to the thalamus, composed of a series of short neuron chains. Hence in many cases in man and animals, after complete hemisection of the spinal cord, the loss of sensibility to pain on the opposite side of the body below the lesion, may only be temporary. In time there may be a more or less perfect restoration of pain conduction, showing that the homolateral side of the cord is able to supplement or replace the heterolateral path.

From what has been said it will be apparent that the paths, mediating pain and temperature sensibility, cross promptly

to the opposite side of the cord and ascend in the dorsal (lateral) spino-thalamic tract. The path for touch crosses more gradually, but finally comes to lie in the ventral spino-thalamic tract of the opposite side; while the proprio-ceptive impulses from the muscles, joints, and tendons, as well as some elements of tactile sensibility, are carried upwards on the same side of the cord by the long ascending axons of the dorsal root fibres, which terminate in the gracile and cuneate nuclei. (Ranson.)

Conduction of Pain from the Skin. It is obvious that both the individual self preservation, as well as the evolution of the race, demand a protective mechanism within the skin which shall warn the individual of nocuous stimuli, or stimuli calculated to endanger the life of the individual. This protective mechanism is provided by the skin's property of transmitting impulses which are translated as "pain." The possession of such a "sense" is, therefore, a physiological property, that is to say, the phenomena of pain are aroused in the skin normally, and not as a result of disease, as is the case with visceral pain. It seems to the author to be extremely important to make this distinction, because it affects the whole neurological study of the transmission of pain impulses from the skin, where its occurrence is a normal physiological sense, and from viscera, where its transmission should never occur in health, but only as a result of disease.

Pain, as an extero-ceptive sense of the skin, is, therefore, as widely distributed throughout the skin as any other cutaneous sense, but there is insufficient evidence as to the manner in which it is aroused, as also of the central paths followed. Pain receptor organs within the skin are quite unknown, as are also special pain tracts. Ranson has recently put forward the suggestion that the unmyelinated fibres of the spinal nerves and dorsal nerve roots are the pain fibres. These terminate in the grey matter of the spinal cord almost immediately after their entrance therein, and in this respect correspond to the known course of axons carrying painful impulses. Further, these unmyelinated axons are found chiefly in

cutaneous nerves, although a few run in muscular branches, which coincides with the much greater sensitiveness of the skin than of the deeper tissues. If this view of Ranson be correct it seems to solve some of the existing difficulties in the interpretation of pain phenomena from the skin, and to fall into line with other known facts. Amongst these may be mentioned the following:

If pain impulses from the skin be transmitted over unmyelinated axons, special pain receptor organs—and these have not yet been found—become unnecessary, because the naked axon itself becomes the receptor. Further one axon could collect, by means of peripheral ramifications, from relatively large areas of skin, so that there would not require to be an unnecessarily large number of such axons.

As these unmyelinated axons terminate, according to Ranson, in the grey matter of the spinal cord immediately after their entry therein, they transfer their impulses to the secondary neurons of the dorsal spino-thalamic tract, which becomes the spinal cord tract for such impulses, and there is thus no necessity for special pain tracts.

The unmyelinated axon is one of the oldest evolutionary types of conducting axon, and protective pain impulses are the earliest and most primitive of such protective mechanisms, and would thus make use of such type of axon.

Head and his colleagues regard those sensations which they term protopathic, as being primitive in character, and the first to appear in the phylogenetic series, and it is to this group that, according to them, cutaneous pain belongs, and it is well known that nerve fibres in their earliest phylogenesis are unmyelinated.

Pending direct experimental evidence, Ranson's view is, at least, supported by broad neurological facts and affords a working hypothesis of the transmission of protective pain impulses from the skin, which thus fall into quite a different category from impulses of visceral pain aroused by disease, most probably from aberrant stimuli over receptor neurons and an overflow therefrom.

Burning pain in the skin would, on this view, result from simultaneous stimulation of the unmyelinated cutaneous axons, and of the myelinated axons from the receptor organs of the warm spots. Throbbing pain would result when the cutaneous vessels are dilated and the part is tense with effused lymph, so that each pulse of the vessels would stimulate the unmyelinated cutaneous axons, as well as the tactile receptor organs.

All cutaneous extero-ceptive impulses having reached the thalamus, in the manner described in this chapter, are finally transferred to the neo-pallium of the cerebral cortex by the thalamo-cortical neurons.

CHAPTER IX

THE INTERSEGMENTAL TRACTS OF THE SPINAL CORD

The Dorsal Spinal Nerve Roots. All receptor impulses reach the spinal cord by receptor neurons which enter through the dorsal spinal nerve roots. Entero-ceptive axons from viscera, proprio-ceptive axons from muscles, tendons, and joints, and extero-ceptive axons from the skin all enter the cord by this path. As it enters the cord each dorsal spinal nerve root can be seen to separate into a larger medial division, and a smaller lateral, the former being composed of medullated axons, and the latter of unmyelinated. The *medial myelinated division* is composed of relatively large axons, some of which run into the posterior or dorsal white funiculus, and form there the gracile and cuneate tracts. The *lateral unmyelinated division* composed chiefly of non-medullated receptor axons of the autonomic nervous system, and, according to Ranson, of pain axons from the skin, passes partly into the grey matter itself, and partly into the tract of Lissauer. Most, if not all of these entering receptor axons divide, in the cord, into ascending and descending branches.

According to Ingbert there enter each side of the spinal cord, through the 31 dorsal spinal nerve roots, 653,000 axons. Even on Stilling's lower estimate of 504,000 axons, it follows that each one of the dorsal nerve roots must transmit centrally about 18 to 20 thousand axons. On entering the spinal cord these divide, as just stated, into ascending and descending branches. The *ascending* branches convey those proprio-ceptive and extero-ceptive impulses already described, and the axons concerned form either directly or indirectly the tracts already mentioned. The *descending* branches are short, do not extend over more than two, three, or four segments of the

cord, and apparently serve the purpose of linking up lower segments of the spinal cord, and of forming peripheral-nerve spinal-cord or somatic reflex arcs. The shortest of these terminate at once in the grey matter of the cord, and take part in the formation of the reflex arcs of the segment. Others descend and form small tracts, such as the inter-fascicular tract and the septo-marginal tract. It consequently follows that the entrant dorsal spinal nerve roots are responsible, not only for the great proprio-ceptive and extero-ceptive tracts already described, but for the following in addition:

- The somatic reflex arc.
- The intersegmental tracts of the spinal cord.
- The interfascicular tract.
- The septo-marginal tract.
- The tract of Lissauer.

The Somatic Reflex Arc. The somatic reflex arc, so-called in opposition to the visceral autonomic reflex arc, is an example of Cajal's third type of arc, namely, the epoch of the inter-segmental reflex neuron. (See page 8.) It consists, theoretically, of three neuronic elements, a receptor neuron, a connectant or internuncial neuron which does not pass out of the spinal cord but is confined thereto, and an effector neuron. Even as thus simply expressed there are some very important structural differences between the somatic arc and the autonomic. These may be tabulated as follows:

SOMATIC ARC	AUTONOMIC ARC	Spinal Cord
Receptor neuron.	Receptor neuron.	
Peripheral process.	Peripheral process.	
Cell station.	Cell station.	
Central process.	Central process.	
Synapse.		
Connector neuron.		
Associational or		
Commissural in type.		
Synapse.		
Effector cell station.		
Ventral grey horns.		
Common effector axon.		
	Synapse.	
	Effector cell station.	
	Preganglionic in lateral grey horns.	
	Preganglionic axon.	
	Synapse.	
	Postganglionic neuron.	
	Other synapses and effector neurons.	

The somatic arc has thus two possibilities of branching discharge within the spinal cord, the autonomic only one.

The somatic arc has its receptor and effector neurons linked by a connector neuron, the autonomic arc has no such link.

The somatic arc has but one effector neuron, which passes without interruption from the cell station to the effector

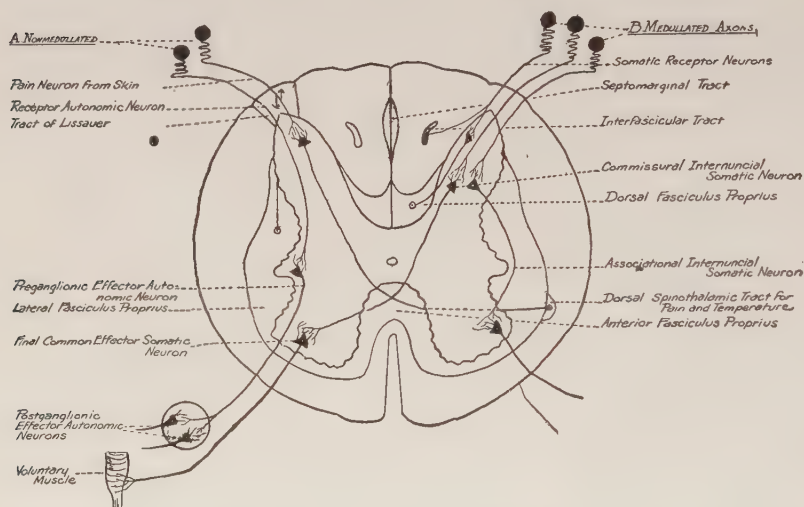


FIG. 29.—Scheme to show: A, differences between autonomic and somatic arcs; B, formation of the fasciculi proprii; C, probable mode of conduction of pain from the skin. See pages 96, 119, 123, 125, 126.

organ, the autonomic arc possesses at least two effector neurons—pre-ganglionic and post-ganglionic, with synapses between.

The somatic arc allows of greater possibilities of central control than the autonomic, inasmuch as it is furnished with two centrally situated synapses, whereas the latter has only one.

The somatic arc concentrates its effector effort on the one spot in response to many stimuli, the autonomic arc gives wider reactions to fewer stimuli.

As regards the *connector* or *internuncial* neurons of the somatic reflex arc, it seems most probable that, from the cell

station in the grey matter, the axon passes out into the white matter, in which it runs up or down the cord, or both, for two or three segments of the cord, in short longitudinal tracts, termed *fasciculi proprii*, thus bringing the receptor neuron into physiological contact with effector neurons of different segmental levels. Further such connector or internuncial neurons may be confined to their own side of the cord, in which case they are termed *associational* neurons, or they may pass over to the opposite side of the cord, when they are termed *commissural* neurons. As most, if not actually all, of the somatic receptor neurons which enter the spinal cord through the dorsal nerve roots, appear to divide, within the cord, into ascending and descending branches, it appears to follow that the nerve impulses conducted may be transmitted to the effector neurons of the same and other segments of the cord by one or other of two short circuits—either by the tracts formed by the descending divisions of the receptor neurons, or through the connector neurons in the *fasciculi proprii*.

The Fasciculi Proprii or Intersegmental Tracts of the Spinal Cord. The *fasciculi proprii* or intersegmental tracts of the spinal cord are composed of short axons which immediately surround all portions of the grey matter. The axons which compose them run in both directions, upwards and downwards, over two, three, or four segments of the cord, and arise from cell stations within the grey matter. Prior to their termination the axons re-enter the grey matter to establish their synaptic connections with effector and other neurons. These tracts probably include all the connector neurons of the numerous somatic arcs; many of the descending divisions of the entering dorsal root receptor axons; some of the shorter axons of such tracts as the spino-thalamics, and they may also possibly provide the neuronie mechanism for the overflow of receptor impulses from the autonomic or visceral system to the somatic under some physiological, and many pathological, conditions.

As has already been stated the neurons of the *fasciculi proprii* may remain on their own side of the cord (*associa-*

tional), or cross over to the opposite side (commissural). The associational type will be the instruments of unilateral reflexes; the commissural of crossed reflexes. Incoming receptor impulses may thus be transmitted by means of the connector neurons of the fasciculi proprii up or down the cord, or may be more immediately transferred to effector neurons of the same segment of the same (associational) or opposite (commissural) sides. It is further possible that, as the fasciculi proprii link together all segments of the cord, they may, under certain conditions, provide an alternative neuronie pathway to other more distinctly functional tracts, especially under abnormal or pathological conditions.

As the fasciculi proprii are found in all three white columns of the cord they are differentiated, anatomically, as the ventral, lateral, and dorsal fasciculi respectively, and in lesions of the cord they undergo an incomplete degeneration for some short distance above and below the section.

The Interfascicular and Septomarginal Tracts. The interfascicular or comma-shaped tract and the septomarginal tract or oval bundle are two small tracts which lie within the dorsal white funiculus, and are apparently formed by some, at least, of the short descending divisions of the entering dorsal spinal nerves. In this case they probably may be regarded as outlying portions of the fasciculi proprii system. They undergo descending degeneration, and do not descend in the cord for more than two, three, or four segments. By means of connector neurons within the fasciculi proprii they probably make synaptic contact with effector neurons at lower levels, and thus form part of somatic arcs, in which the brain is cut out, with the consequent establishment of a sensori-motor short circuit. Like all other tract-forming axons in the spinal cord, they give off collaterals to the intermediate segments over which they pass, and so provide still more neuronie arcs for the passage of nerve impulses.

The Tract of Lissauer. The tract of Lissauer (dorso-lateral tract or marginal bundle) lies between the apex of the dorsal grey column and the periphery of the cord, and is apparently

formed almost entirely of the non-myelinated axons of the lateral division of the entering dorsal nerve root. It would thus appear to consist of non-medullated receptor axons belonging to the autonomic system, and of the cutaneous pain fibres of Ranson. This view is supported by the fact that the shape and size of the tract vary considerably at different levels of the cord. Those of its axons which ascend do not extend over more than two or three segments of the cord, and terminate about the cells in the substantia gelatinosa of the dorsal grey column, that is, in exactly the spot at which commence the neurons of the dorsal (lateral) spino-thalamic tract over which cutaneous pain is conducted. The tract does not undergo degeneration in locomotor ataxia.

The descending fibres of the tract of Lissauer are probably of the usual inter-segmental character.

Summary of the Entering Receptor Dorsal Nerve Root Axons. The many thousands of receptor axons which enter the spinal cord by every dorsal spinal nerve root would appear to belong, functionally and in the main, to one or other of the following groups:

Simple reflex arcs, autonomic and somatic. Autonomic reflex arcs with a receptor neuron terminating in the spinal cord, and establishing one synaptic connection with a pre-ganglionic effector neuron, that is, an example of Cajal's epoch of the reflex arc. Such an arc gives an immediate response over a wide area to a single receptor impulse.

Somatic reflex arcs with a receptor neuron terminating in the spinal cord, and establishing a synaptic connection with a connector or internuncial neuron. This, in turn, establishes a second synaptic connection with an effector neuron which proceeds without interruption, and unlike the autonomic arc, to the seat of re-action. Such a type of reflex gives a localised response to many stimuli, and affords, by means of its two spinal-cord synapses, greater possibilities of overflow of nerve impulse and of the receipt of aberrant nerve impulses from other sources. Further, this type of reflex arc may cause impulses to be transmitted to effector neurons of

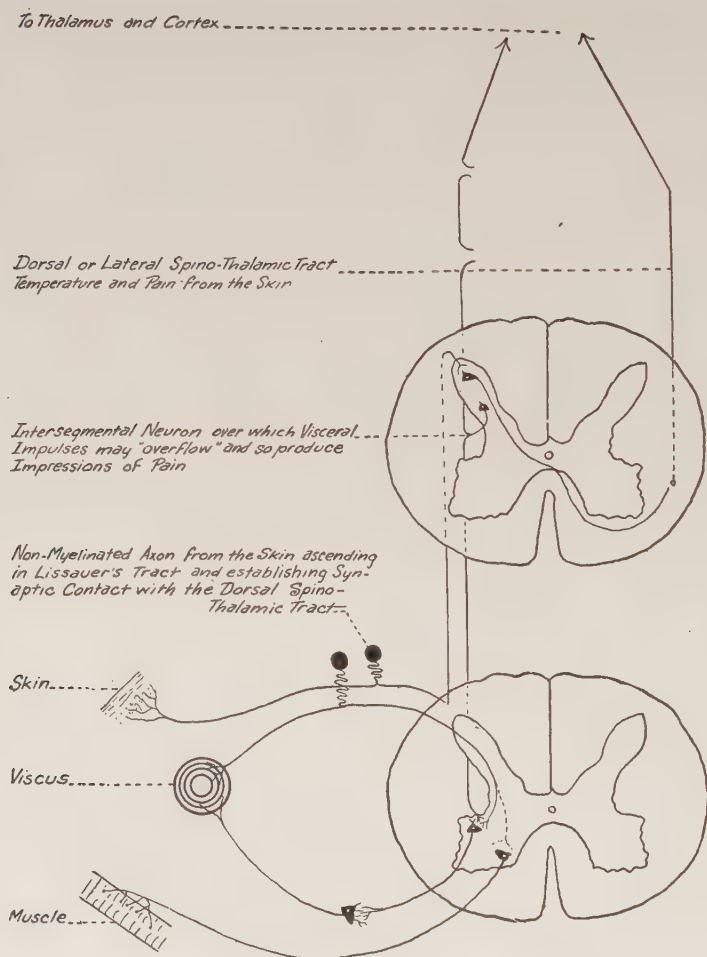


FIG. 30.—A scheme to show hypothetical pathways for the central conduction of cutaneous and visceral pain. See pages 96, 113, 118, 119.

more than one segment, on account of the interpolated neuron with the additional synapses, but the physiological re-action is still that of the simple reflex. The connector neurons probably form, in large part, the tracts known as the fasciculi proprii.

This type of neuron arc, where the receptor and effector limbs are united by a connector neuron, is an example of Cajal's epoch of the intersegmental reflex neuron, and appears to be the fundamental basis of the construction of the nervous system of all animal forms in the vertebrate class. It is extremely significant that the human cerebrum is largely formed of the spinal cord type of association and commissural neurons, that such are *not* found in the cerebellum, where a different type of connector neuron is utilised, also made use of in the cerebral cortex, and that in the brains of lower mammals, such as the kangaroo, only the associational type of connector neuron is present, there being no corpus callosum.

Cerebellar arcs. The entering receptor dorsal nerve root axons here concerned terminate around the neurons which form the dorsal and ventral spino-cerebellar tracts of Flechsig and Gowers. They excite co-ordinated reflexes in the cerebellar cortex of an unconscious character, and are proprioceptive in type. Such arcs are examples of Cajal's epoch of the supra-segmental reflex neuron.

Cerebello-cerebral arcs. The entering receptor axons here form the gracile and cuneate tracts, which terminate in the medulla oblongata around the nuclei of those tracts, whence the impulses are transferred to both cerebellum and cerebrum. The impulses so transmitted are those of muscle sense, and possibly also include impulses leading to tactile discrimination, and to the recognition of size, shape, form in three dimensions, impulses of vibration and of weight. Such impulses are proprioceptive in character, and arouse subconscious sensations. Arcs of this character are examples of Cajal's epoch of the supra-segmental reflex neuron.

Cerebral arcs. The axons concerned form the spino-thalamic tracts and reach the cerebral cortex in which conscious-

ness is aroused by the extero-ceptive impulses transmitted. By these pathways are transmitted impulses of heat, cold, touch, pressure, and cutaneous pain, and they cross over to the opposite side. Arcs of this character belong to Cajal's epoch of the psycho-associational neuron, because the impulses transmitted have to be synthesised, stored up, and translated in the cerebral cortex.

CHAPTER X

THE EFFECTOR OR "MOTOR" PATHWAYS

The Re-actions to the Environment. Every animal form possesses the power of changing the relationship of its bodily form to the environment in the manner best suited to its individual needs, and in accordance with the imperious necessity of self-preservation in the struggle for existence. The receptor mechanisms already described inform the animal of the conditions of its own body, and of the state of its external surroundings, that is, of the environmental habitat. The effector mechanism enables the animal to adapt itself to this constantly changing environment, and in the case of the lower animals with a simple nervous system, and of spinal cord animals, the neuronc machinery employed is so simple that the effector changes which will follow any particular stimulus can be predicted with certainty. In the case of man with his highly complex brain and complicated nervous system, which enables the reaction to the receptor stimulus to be infinitely delayed, altogether arrested, or overlain by subsequent incoming receptor impulses, any such prediction becomes impossible, except on the broadest possible lines. Further, the incoming receptor impulses are, in man, as has been seen, so numerous and complicated, as to require a complex effector apparatus to give the appropriate motor response to the receptor stimuli, and this complexity is still further increased by the assumption of the erect attitude, and the necessity for the balancing of the body in space.

The Effector or "Motor" Pathways. The control of voluntary muscles is, in man, an extremely complicated act, and requires an equally complicated neuronc mechanism. Into this mechanism the brain and pyramidal system largely enter, so much so indeed that in the clinical study of disease, the

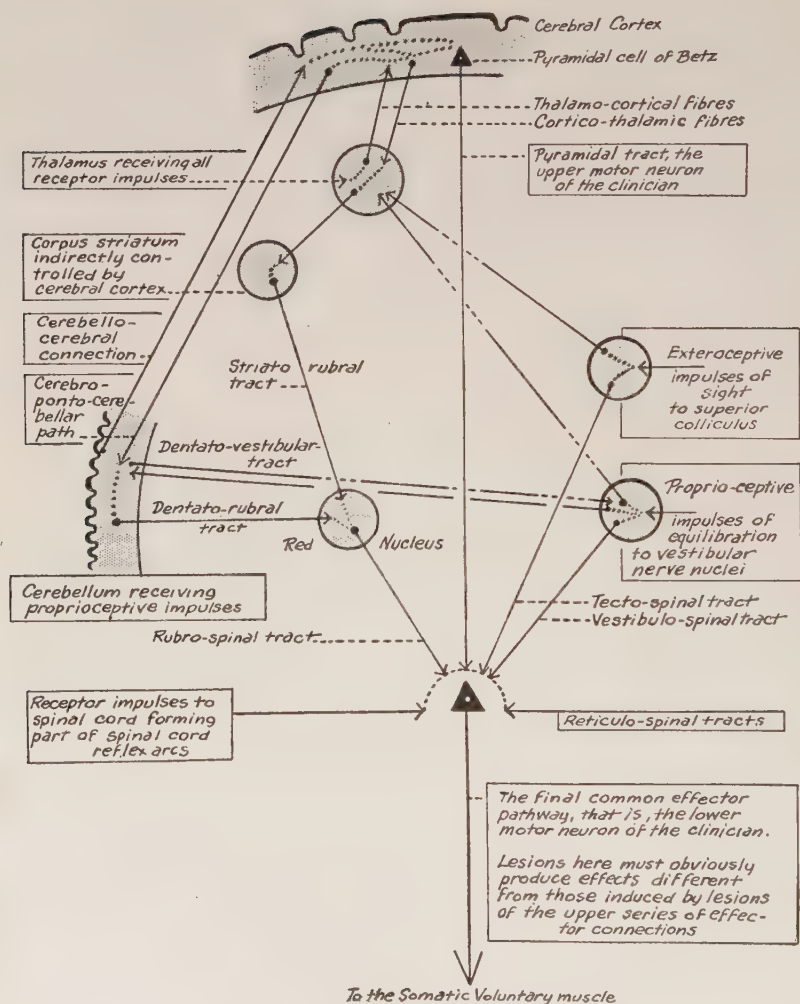


FIG. 31.—A scheme to show the various impulses controlling the voluntary muscular activities and the pathways pursued.

conception of an upper and a lower neuron has too long dominated the situation and has distracted attention from the many other and equally important neuronie mechanisms which go to the control of voluntary muscular action. Although it is necessary to describe these several effector mechanisms as separate entities, they must not be visualised as functioning separately. They work as a whole and no single part of the mechanism can be disturbed, as a result of disease, without a corresponding impairment of the whole.

The several portions of the effector pathway in man may be set forth as follows:

From the cerebral cortex.

The cortico-spinal tracts, also known as the pyramidal system, or the upper motor neurons.

From the corpus striatum.

The striato-rubral tracts to the red nucleus, and thence through the rubro-spinal tracts.

From the organ of vision. (Through Optic nerve.)

To the superior colliculi (superior quadrigeminal bodies), and thence through the tecto-spinal tracts.

From the semicircular canals of the ear. (Through Vestibular nerve of equilibration.)

To the vestibular nerve nuclei, and thence through the vestibulo-spinal tracts.

From the cerebellum.

Through the dentato-rubral tract to the red nucleus, and thence through the rubro-spinal tracts.

Through the dentato-vestibular tract to Deiter's nucleus (vestibular nerve), and thence through the vestibulo-spinal tract.

From the large effector or "motor" cells in the reticular formation of the brain stem.

Through the reticulo-spinal tracts.

From the segments of the spinal cord.

Through the somatic and autonomic reflex arcs.

All these tracts, and possibly others, converge on, and convey their impulses to, the final common effector pathway, which is, in the case of the spinal cord, the effector neuron which passes out through the ventral spinal nerve roots into the peripheral nerves. It has its cell station within the ventral grey column of the spinal cord, and is thus the lower

motor neuron of the clinician. In the cases of the cerebral effector nerves the cell stations lie within the so-called nuclei of origin of these nerves, and the axons within the cerebral nerves themselves.

It is thus obvious that the effector apparatus is much more complicated than the clinical conception of an upper and lower motor neuron would seem to imply. It is further known that the pyramidal pathway (upper motor neuron) is not the only pathway for voluntary control of muscles from the cerebral cortex. This alternative pathway is sometimes known as the *extra-pyramidal path*, the exact composition of which is not known with certainty. By others again the term "extra-pyramidal" is employed to designate all known effector tracts, other than the pyramidal, excluding, of course, the final common effector pathway. The "upper motor neuron" is merely the pyramidal tract, which, in its turn, is only a part, and not necessarily even the most important part of a complex functional effector apparatus, whilst the "lower motor neuron" is the final common effector pathway, the final distributor of all the complex impulses which go to control muscular activity.

Importance of the Effector Apparatus as a Single Working Whole. Both Ranson and Walshe, amongst many others, stress the clinical importance of regarding the human effector mechanism as a harmoniously working single entity. Ranson says we must not think of the individual parts of this complex mechanism as functioning separately, since each of these effector impulses contributes its share to the control of the final common effector neuron, upon which all these effector pathways converge. Only by keeping this fact constantly in mind can the effector functions be properly understood. Walshe puts the matter in another way. In stimulation experiments on the effector portion of the cerebral cortex in which the pyramidal tracts arise, we see a complex motor mechanism at work under the influence of an abnormally induced, crude form of hyperactivity of this part of the effector mechanism. Conversely, after destructive lesions of the

cerebral effector cortex we observe it at work liberated from the control of this part of the mechanism and deprived of its actual co-operation.

On the other hand, the grave muscular disturbances resulting from lesions in the basal ganglia, and especially the striate body, with little or no involvement of the cortico-spinal pyramidal tracts (paralysis agitans, bilateral athetosis, and progressive lenticular degeneration) have recently called attention to the importance of the striate body effector pathways. In these diseases voluntary movements are impeded by tremor, rigidity, and athetosis; and in all probability these disturbances arise because the pyramidal system is deprived of the co-operation of one of its functional partners in the motor combine.

Even after cerebral control has been entirely eliminated in the dog by decerebration, many reflex functions remain, which represent the unguided activity of reflex arcs in the effector mechanism, and we now know that a similar independent reflex activity may occur in the spinal cord of man after total transverse lesions.

Effector Pathways from the Cerebral Cortex. The effector pathways from the cerebral cortex are through the well-known *lateral* and *anterior cortico-spinal* or *crossed* and *direct pyramidal tracts*, which are the great effector pathways for voluntary movements.

The neurons which form these tracts have their nerve cells in the pre-central portion of the cerebral cortex, and are known as the giant pyramidal cells of Betz. Their axons pass through the brain, brain stem, and spinal cord to end in arborisations around the effector cells in the ventral grey columns of the cord, that is, around the cell bodies of the final common effector neurons.

The axons of the pyramidal tracts number some 160,000, though this number differs considerably in different animals and even in human individuals. They constitute the pathway from the cortex for those impulses which preside over voluntary movements, and particularly those acquired move-

ments which call for skill and finesse. If the human individual be lacking in a sufficiency of these axons, his skill of movement will be correspondingly diminished.

The *lateral cortico-spinal* or *crossed pyramidal tract* is situated in the lateral funiculus of the spinal cord. Its axons arise from the giant pyramidal cells of Betz in the precentral cortex. Passing through the brain and brain stem, they enter the pyramid of the medulla, whence their name of pyramidal

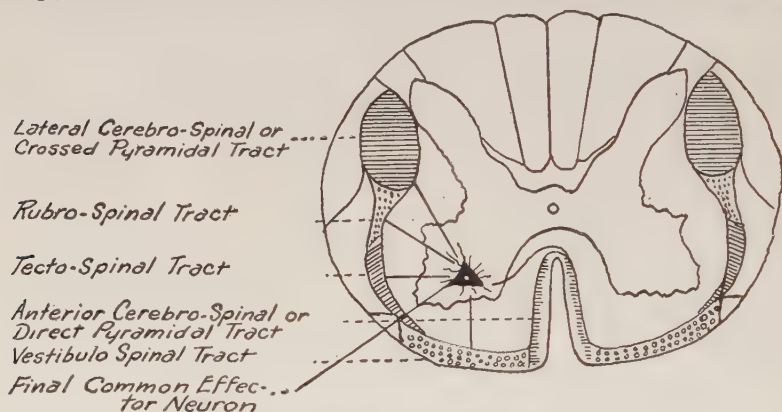


FIG. 32.—The effector tracts of the spinal cord converging on the final common effector neuron. See pages 131, 135, 138, 139, 141, 142.

tracts, decussate, that is, cross over to the opposite side in the great "motor" decussation of the pyramids, and thereafter take up the position in the spinal cord already indicated, and terminate in the manner described. Seventy-five percent of the axons pass through this tract.

The *anterior cortico-spinal* or *direct pyramidal tract* comprises the remaining 25% of the cortical effector axons. From the cerebral cortex to the pyramids of the medulla, the course is as just described. These axons do not decussate in the decussation of the pyramids, but continue to traverse the spinal cord on the same side as that from which they arose in the cerebral cortex. They form a small tract which lies lateral to, and parallel with, the ventral median fissure. In each successive segment of the cord some of the fibres of this tract cross, through the ventral white commissure, to

terminate around the cells of the final common effector neurons of the ventral grey columns of the cord. The tract is thus a delayed crossed effector tract, and the consequence is that eventually most, if not all, the axons of these two tracts cross over to the side opposite to that whence they arose.

Both tracts run throughout the length of the spinal cord, but naturally their area diminishes in every successive segment of the cord, as they are constantly giving off axons to the nerve trunks. As, in the main, the tracts are crossed, it follows that the right cerebral cortex controls the left-sided musculature and *vice versa*.

The pyramidal system of effector axons probably contains some few which do not decussate, and the whole system differs, in different vertebrates, in the extent of its development and in its exact location in the cord. It attains its highest development in man and the anthropoid apes.

The pyramidal tracts are undoubtedly the main paths by which impulses controlling voluntary muscles pass from the cerebral cortex to the various spinal segments, and on through the final common effector neurons through the ventral roots of the spinal nerves to the various parts of the body supplied by those nerves. Paralysis resulting from section of the pyramidal tracts is not complete and persistent. There is, therefore, some other path by which volitional impulses arising in the cortex can reach the effector cells of the cord. Halliburton thinks this alternative route may be through the tract of Lowenthal, and other descending axons in the ventral white funiculus, and ventral parts of the lateral white funiculus. It seems, however, to be equally possible that the longer axons in the fasciculi proprii may supply this alternative route. As the pyramidal system is a comparatively late evolutionary addition to the nervous system and is not found at all in vertebrates lower than mammals, that is, is confined to animals with a neo-pallium, it does not appear at all improbable that some older and other pathway may exist for the passage of volitional impulses, besides the pyramidal tracts themselves.

Effector Pathways from the Striate Body. In recent years it has been clearly demonstrated that the pyramidal effector pathways are not the only ones concerned in the control of voluntary muscles. The cerebral cortex appears to be indirectly connected, probably through the thalamus, with the striate body, the functions of which are "motor," and appear to exert a steadying influence upon voluntary movements. From the globus pallidus of the lentiform nucleus (part of the striate body) axons would appear to pass as *striato-rubral pathways* to the red nucleus, and thence within the *rubro-spinal tracts* through the spinal cord and peripheral nerves to the voluntary muscles. The important, but indirect, cortico-striate connections are more fully considered later. (See page 438.)

As regards the *striato-rubro-spinal pathway* the axons pass from the globus pallidus of the lentiform nucleus to the red nucleus without decussation. As the subsequent pathway, the rubro-spinal tract, eventually decussates in the decussation of Forel, this connection is a complete contra-lateral connection, that is, it links together one side of the cerebral hemisphere with the opposite side of the cord.

Effector Pathways from the Organ of Vision. It is obviously extremely important that visual impressions should be utilised in muscular control. These central connections are brought about through optic nerve terminations in the superior colliculus (superior quadrigeminal body), whence arise a fresh series of axons which descend through the brain stem and spinal cord as the tecto-spinal tract, thus forming a direct visuo-spinal connection, independent of the cerebral cortex.

The *tecto-spinal tract* or *ventral longitudinal bundle* has its cell station in the superior colliculus (superior quadrigeminal body). The axons decussate and pass thence through the mid-brain, pons, and medulla, in close relationship to the medial longitudinal tract, to the spinal cord, where they end in arborisations around the cells in the ventral grey column of the cord of the final common effector pathway (lower motor neuron). In its descent the tract is partly intermingled with the axons of the rubro-spinal tract, and partly lies within

the ventral white funiculus. It gives off collaterals to the nuclei of the "motor" nerves of the eyeball, as well as to the medulla. It would thus seem to serve the purpose of protecting the eye by means of reflex movements of suitable muscles, and of forming a supra-segmental apparatus for the maintenance of ocular position for fixed gaze, in addition to assisting in the control of voluntary muscles.

Effector Pathways from the Semi-circular Canals (Equilibration). Just as impressions of sight must be utilised in the control of voluntary muscles, so also must impulses from the sense of equilibration be utilised for the muscular efforts which preserve the balance of the body in space. Such impulses are transferred from the receptor organs in the semi-circular canals of the ear along the vestibular nerve to the recipient nuclei of that nerve within the pons, that is, to the lateral and superior nuclei, or the nuclei of Deiters and Bechterew. Here arise a fresh series of neurons which descend to the cord and form the vestibulo-spinal tract.

The *vestibulo-spinal tract* or *the dorsal longitudinal bundle* has its cell station in the nuclei just mentioned. The axons descend through the pons and medulla, as both crossed and uncrossed, probably chiefly uncrossed, to the spinal cord, where they form a small tract ventral to the tecto-spinal tract. They end in arborisations around the cells of the final common effector neurons, and thus appear to bring vestibulo-equilibratory control to the voluntary muscles.

Effector Pathways from the Cerebellum. It has already been seen (see page 102) that the cerebellum is the great correlation centre and storehouse for those proprio-ceptive impulses from muscles, tendons, joints, and the semicircular canals of the ear, whose function is the maintenance of equilibrium, posture, and the tone of muscles. Having received and stored up these impulses the cerebellum, in response to impulses from the cerebral cortex, conveyed over cerebro-ponto-cerebellar neurons, discharges effector impulses which play an important part in the control of muscular activity. The pathways by which these impulses are conveyed to the peripheral nerves are through the dentato-rubral tract, and

thence to the spinal cord by the rubro-spinal tract, and also through the dentato-vestibular tract to Deiters nucleus (vestibular nerve) and thence on through the vestibulo-spinal tracts.

The *dentato-rubral tract* is a supra-segmental tract, and is not, of course, a tract of the spinal cord, but as it is an essential first link in the cerebellar-spinal-cord pathway it is necessary to consider it here. It consists of the axons of cells situated in the dentate nucleus which receive impulses from the Purkinje cells. After decussation in the superior cerebellar peduncles (*brachia conjunctiva*) the axons pass over to the red nucleus of the opposite side. From the red nucleus the pathway is by way of the rubro-spinal tract to the spinal cord, and as these axons again decussate in the decussation of Forel, the cerebello-rubro-spinal connection is an ipsilateral one, that is, it connects one side of the cerebellum with the same side of the cord by means of decussation and re-decussation.

The *dentato-vestibular tract* is a similar supra-segmental connection between the dentate nucleus and the vestibular nerve nuclei, whence cerebellar impulses are carried on along the vestibulo-spinal tract already described.

The *rubro-spinal tract*, also known as *Monakow's bundle*, the *pre-pyramidal tract*, or the *intermedio-lateral tract*, apparently forms a common spinal cord path for impulses coming from the cerebellum and the striate body. The cell station is in the red nucleus of the tegmentum of the mid-brain. The axons decussate almost at once, in the ventral tegmental decussation of Forel and descend through the pons and medulla into the spinal cord. Within the cord the tract occupies a distinctive triangular area in the lateral column, on the ventro-lateral side of the lateral cortico-spinal (crossed pyramidal) tract, the two systems being more or less intermingled. The axons terminate in arborisations around the cell bodies of the final common effector neurons (lower motor neurons).

As the rubro-spinal tract is the spinal cord link for impulses coming from the cerebellum and the striate body it in-

troduces into the regulation of muscular activity those functional properties which are inherent therein, that is, the cerebello-rubro-spinal connection acts in the interests of the synergic control of muscles, and the striato-rubro-spinal connection is concerned with automatic associated control of muscles. The impulses conveyed by the rubro-spinal tract probably control stock movements, such as standing, sitting and walking, and exaggerate muscular tone. It is largely by this tract, that a patient, whose pyramidal tracts have been destroyed in the brain, may still be able to get about with difficulty. The tract is also not improbably concerned in the reflex mechanism of spastic rigidity of muscles, which occurs in certain lesions of the brain.

Effector Pathways Through the Reticulo-Spinal Paths. It is known that practically all levels of the brain-stem and spinal cord are connected together by a series of short neurons, and that many "motor" or effector cells are found scattered through the reticular formations of the pons, medulla, and cord. The term *reticulo-spinal* has, therefore, been suggested for such tracts, the axons of which, instead of pursuing separate paths through the cord, are more probably intermingled with the medial longitudinal tract of the brain stem and the fasciculi proprii of the cord. Exactly where the impulses stimulating the reticulo-spinal tracts originate is uncertain, but as most of the ascending receptor tracts of the cord give off collaterals to each segment of the cord and brain stem, it is possible that such may be the source of stimulation. In this case the reticulo-spinal tracts would form an important part of the spinal cord reflex mechanism, and may even provide an alternative, but somewhat imperfect, pathway, to the pyramidal system itself, as well as furnishing a path for many of the as yet imperfectly understood, protective reflex mechanisms mediated through the mid-brain, pons, medulla, and cord.

Effector Pathways Through Spinal Cord Segments. Throughout the whole of the spinal cord, provision is everywhere made for the immediate transference of an incoming

receptor impulse to an outgoing effector neuron, and the mechanism involved is that of the somatic and autonomic arcs, as has already been fully considered.

The Final Common Effector Pathway. The final common effector pathway is synonymous with the "lower motor neuron" of the clinician. To this are transmitted the various impulses conveyed by the pathways just described, all of which converge upon the final common effector pathway. In the case of the spinal nerves the cell station is in the ventral grey columns of the cord, and the axon passes out through the ventral roots of the spinal nerves, and thence along the peripheral nerve to the muscle concerned. In the case of the cerebral effector nerves the final common effector neuron has its cell station within the nuclei of such effector cerebral nerves, whilst the axons form the nerves themselves.

Functional Significance of the Effector Pathways. For the correct functional working of a voluntary muscle a variety of nerve impulses must be focussed on the final common effector pathway, which in some, as yet not understood manner, fuses all these influences into itself and transmits the common product to the muscle. Amongst these different impulses, which are essential to muscular activity, are idio-dynamic control, reflex and tonic control, associated segmental control, equilibratory and synergic control, automatic associated control, and voluntary and inhibitory control. (Tilney and Riley.)

Idio-dynamic control is dependent upon the integrity of the cell body of the final common effector neuron itself, and this function is exercised quite independently of all other sources of nerve impulses within the nervous system. Disease or destruction of the cells concerned is followed by impairment or disintegration of the associated muscles. In fact the life and integrity of the muscle depend on the integrity of the cell body of the final common effector neuron. When the muscle is deprived of this idio-dynamic control it ceases to live as muscular tissue and tends to revert to the simpler elements to which it is genetically related, that is, connective tissue.

Reflex and *tonic control* are the special properties of the somatic and autonomic reflex arcs already described. The muscle is constantly transmitting proprio-ceptive and receiving other impulses over these arcs, and is thus maintained in a definite state of contraction, known as *myotonus*. In consequence of this reflex connection the muscle is also subject to another variety of regulation, termed *reflex control*, which regulates reflex action, as typically seen in the well-known patellar reflex. It is not improbable that tonus is the special property of the autonomic arc, and reflex control of the somatic.

Associated segmental control is necessitated by the fact that every muscle is regulated by more than one nerve cell. The control of any muscle is, therefore, dependent upon the integrative or combined action of a number of nerve cells. Connections between these cells, so that an impulse arising in one cell may simultaneously stimulate all other cells presiding over the muscle, are an essential, and may be either intra-segmental, inter-segmental, or trans-segmental.

Equilibratory control from the semicircular canals is essential to the maintenance of bodily equilibrium in locomotion, and, notwithstanding that the cerebellar connection is an indirect one, it appears that the cerebellum plays an important part in this controlling mechanism, as it certainly does in the *synergic control* of muscles.

Associated automatic control of muscular action appears to be inborn in the individual, and does not require any special education, as does the act of walking. Such movements seem to have been designed for the accomplishment of definite purposes, and to be handed down from progenitor to offspring without any special effort on the part of the individual. A typical example of this automatic associated control is seen, in the human being, in the swinging of the arms in definite relation to the movement of the legs. That these movements are not merely the result of gravity is demonstrated by the totally different movements of the arms in a walking match. In the human being this form of automatic

associated movement, which seems to be purposeless, is a relic of the associated movements of the lower limbs in quadrupeds. As a matter of fact there are a very large number of these automatic associated movements in man, and the striate body seems to exercise this control, because in disease of this structure there is a more or less complete suppression of these actions. The tecto-spinal tracts from the superior quadrigeminal bodies would also appear to assist, for they certainly afford the structural basis for the production of associated automatic acts of the eye-lids, eyes, head, and arm, in a defensive mechanism to protect the retina and eye.

Voluntary control of muscles is in a quite different category from automatic associated control, because such individual control has to be learned by means of individual experience and effort. Handwriting, for example, can only be learned after much long-continued individual effort, and in the worse of the cerebral ailments cannot be learned at all. The origin of this control is in the Rolandic area and is transmitted over the pyramidal system of axons. This system, as well as certain others, would also appear to exercise a property of inhibition, that is, of preventing other impulses from reaching the final common effector pathway in too powerful a fashion, as is evidenced in the occurrence of muscular spasticity after certain diseases of the pyramidal system. This property appears to be shared by the striate body, and possibly also the cerebellum.

Lesions of the Effector Pathways. Lesions of the effector pathways are very common particularly of the pyramidal tracts, and of the final common effector pathway.

As regards the *pyramidal tracts* the lesion may be *extra-cortical*, as from pressure upon the pre-central effector cortical area from a hæmorrhage, depressed fracture of the skull, tumours, etc. In such cases the area of the lesion is usually restricted and there ensues a monoplegia, that is, a paralysis of a single part, such as the arm or leg.

The lesion may be *cortical*, as, for example, in uraemia where the bodily poison specially affects the pyramidal cells

of Betz, and the resultant hemiplegia is sometimes difficult to distinguish from that caused by a cerebral hæmorrhage.

The lesion may be *sub-cortical* and is then most usually the result of rupture of the lenticulo-striate artery. If the hæmorrhage be sufficiently severe all the axons of the pyramidal tracts within the internal capsule, here grouped together in a small compass, will be totally cut off and total paralysis of the opposite side of the body, hemiplegia, together with other cerebral symptoms, results.

Damage to the pyramidal system within the cerebral peduncle, pons, or pontine part of the medulla oblongata may also cause hemiplegia, but in these cases those axons given off from the system on the cerebral side of the lesion to the effector cerebral nerves will necessarily escape injury, and the corresponding cerebral nerves will not be paralysed.

In lesions of the pyramidal system *within the brain-stem*, the nucleus of an effector cerebral nerve may also be involved, in which case there would result a *crossed paralysis*—a paralysis of the muscles supplied by the cerebral nerve involved, on the same side of the lesion, and a paralysis of all muscles of the body below the lesion and of the opposite side.

Lesions of the pyramidal tracts *within the spinal cord* may be uni-lateral or bi-lateral, and the resulting paralysis is either homo-lateral or bi-lateral, the latter being the commoner of the two.

Whilst paralysis is the most obvious result of lesions of the pyramidal tracts it is not, especially when the lesion is intracranial, the only phenomenon produced. There are often accompanying mental disturbances of a profound character, illustrative of the diaschisis of von Monakow, which often pass unnoticed.

Amongst the more obvious clinical alterations noticed in *lesions of the pyramidal tracts* are the following:

Wasting of muscles, slight, and only in consequence of disuse, because idio-dynamic control, exercised by the cell body of the final common effector pathway, is unaffected.

Deep reflexes are increased because the inhibiting influence of the pyramidal tracts is removed.

The affected limbs tend to extra *rigidity* on account of the removal of the inhibitory control.

The *electrical reactions* give no obvious changes.

There is a tendency for *contractures* to occur, on account of the myotonic influences from other sources being now uncontrolled.

Lesions of the final common effector pathway, that is, the lower motor neuron, may affect either the cell body of the neuron or the axon. As examples of the former, *acute poliomyelitis anterior* or *infantile paralysis* results from acute inflammatory changes taking place in the cell-bodies of the final common effector neurons within the ventral grey columns of the spinal cord. *Progressive muscular atrophy* is a wasting of muscles from a slow and progressive degeneration of the same cells. Under these and all similar lesions it is obvious that no nerve impulses whatsoever can now reach the muscles, and this is the essential difference between lesions of the final common effector neurons, where *no* impulses reach the muscles, and those of the pyramidal tracts where *most* effector impulses still continue to reach the muscles. In *lesions of the final common effector neurons* the following clinical phenomena, which should be contrasted with those presented by lesions of the pyramidal neurons, may be observed:

Wasting of muscles is always a prominent feature on account of the complete loss of idio-dynamic control.

Reflexes are abolished in the affected segments, because the reflexes can no longer pass through from the receptor to the effector side.

The limbs tend to become *flaccid* as the muscles are now deprived of normal nerve stimuli.

Electrical reactions to faradism and galvanism are modified, and there is frequently a typical "reaction of degeneration."

Irregular *deformities* of muscular contraction are often

present, owing to the complete paralysis of some muscles and the unopposed action of others, that is, the synergic control is now abolished.

Whilst lesions of the pyramidal tracts and the final common effector pathway are the commonest of the effector apparatus lesions, any of the other constituent effector tracts converging on the final common effector pathway may be the seat of disease. For example, lesions of the *globus pallidus* of the striate body may give rise to paralysis agitans; lesions of the *putamen* may produce progressive lenticular degeneration lesions of the *caudate nucleus and putamen*, athetosis, whilst cerebellar disease also produces its own characteristic phenomena. As the red nucleus derives its functional significance from the fact that it brings the cerebellum and the striate body into direct control over the somatic voluntary muscles, it follows that lesions of that nucleus, of the rubro-spinal tract, or of the dentato-rubral or striato-rubral tracts, will modify these functions and produce manifestations of disease. For these phenomena a handbook of nervous diseases should be consulted.

Ventral Roots of the Spinal Nerves. According to Ingbert each ventral root of a spinal nerve contains about 200,000 axons, though Stilling estimates them at slightly over 300,000. These axons belong, perhaps exclusively, to the effector systems of the somatic and autonomic nervous systems, and have their cell stations in the grey matter of the spinal cord, the former in the ventral horn, the latter in the lateral horn; they form, respectively, the final common effector pathways and the pre-ganglionic effector neurons.

The effector neurons of the central or somatic nervous system pass out of the spinal cord from their cell stations through the ventral roots of the spinal nerves, and thence to their destinations through the spinal nerves themselves and their branches. Such axons are naturally more numerous within the cervical and lumbar enlargements of the cord than elsewhere.

The *pre-ganglionic effector neurons* of the autonomic nerv-

ous system, least numerous in the cervical and lumbar enlargements, pass out of the spinal cord from their cell stations through the ventral roots of the spinal nerves, and thence through the white rami communicantes to the ganglia of the autonomic system, where they establish functional contact with the post-ganglionic autonomic effector neurons. It consequently follows that the axons found in the dorsal and ventral spinal roots belong functionally to one or other of the following groups:

Dorsal nerve root.	Ventral nerve root.
Visceral receptor.	Visceral effector.
Somatic receptor.	Somatic effector.

Lesions of the nerve roots must, therefore, involve both systems and produce symptoms accordingly.

Other Tracts in the Spinal Cord. In addition to the well established receptor, connector, and effector tracts of the spinal cord already described, several others have been noted by different investigators, the connections and functions of which are not, as yet, sufficiently established. It is not improbable that some of these are really parts of the reticulospinal pathways already mentioned. Amongst these tracts are the following:

The *bulbo-spinal*, or *olivo-spinal tract*, also termed the *bundle of Helweg*, whose axons arise from cells in the inferior olivary nucleus of the medulla oblongata, and descend close to the ventral nerve roots of the spinal cord. It is only found in the cervical region of the cord, and its destination is unknown.

The *cerebello-spinal tract of Lowenthal*, also known as the *anterior marginal bundle*, is said to arise from cells in the cerebellum, and to descend in the spinal cord to end around the cells of the ventral grey column. By others it is regarded as forming part of an extra-pyramidal system.

Other smaller tracts have also been described in the spinal cord, but are not, as yet, sufficiently substantiated.

Hemisection of the Spinal Cord. Transverse section of one half of the spinal cord in man produces a characteristic com-

plex of symptoms known as the *Brown-Sequard syndrome*. The main clinical phenomena presented are:

1. Below the level of the lesion, and on the same side, there is a spastic paralysis of muscles, with a loss of proprioceptive sensibility.

2. On the opposite side of the body, beginning two or three segments below the level of the lesion, there is a loss of pain and temperature sensibility. According to Dejerine there is everywhere retained tactile sensibility.

3. An absence of sensory or motor phenomena in other parts of the body.

CHAPTER XI

THE GREY MATTER OF THE SPINAL CORD

Microscopic Elements of the Grey Matter of the Spinal Cord. From what has been stated of the numerous tracts of the white matter of the spinal cord, it should be obvious that the grey matter is the seat of the cell-bodies of the neurons which go, in some way, to make up these tracts, or, as secondary neurons, to convey impulses to or from them. The grey matter of the spinal cord is thus composed of nerve cells with their dendrons, of unmyelinated axons, and of smaller numbers of myelinated axons, all supported by neuroglia and richly supplied with capillary blood vessels.

Two types of neurons are found within the grey matter of the spinal cord, Golgi Type I and Golgi Type II, and both types are of the multipolar variety. The *latter* are strictly confined to the grey matter, that is, no part of the neuron passes outside that grey matter, and they thus belong to the internuncial series of neurons. They are chiefly found in the dorsal grey column and particularly in the substantia gelatinosa, but are never very numerous. In this last respect the internuncial neurons of the segmented spinal cord are in striking contrast to the supra-segmental portions of the neuraxis where such neurons are very numerous.

As regards *the spinal cord Golgi Type I neurons* these comprise the bulk of the cells found in the grey matter of the spinal cord, and as they differ in size and position they may be subdivided into three groups.

The *first of these groups* have large cell bodies and are found in the ventral grey columns and their axons pass out of the cord in the ventral roots of the spinal nerves. These are, therefore, the cells of the lower motor neurons or the final

common effector pathway and are the ones affected in acute poliomyelitis anterior. They are most numerous in the cervical and lumbar enlargements because it is from these segments that the limbs have been derived, and hence the cells in these regions of the cord preside over the musculature of the two extremities.

A *second group of Golgi Type I neurons*, with smaller cell bodies, have their cell stations in the lateral grey column of the cord. The axons pass out of the cord through the ventral roots of the spinal nerves and are distributed to the non-striated musculature of the viscera. This group comprises, therefore, the pre-ganglionic effector fibres of the autonomic nervous system.

A *third group of Golgi Type I neurons* have their cell bodies, of small or medium size, scattered through the dorsal grey column of the cord. The axons enter the white matter within which they turn upwards or downwards or divide into ascending and descending branches. Some of the upward series of axons are long and reach higher levels of the neuraxis, as for example, the axons of the dorsal nucleus of Clarke, which run uninterruptedly to the cerebellum as the dorsal spinocerebellar tract. The majority of the ascending axons of this group of cells, as well as most of the descending, only extend over a few segments of the cord, and re-entering the grey matter, establish synaptic contact with other spinal cord neurons. The group comprises, therefore, the axons of the fasciculi proprii. Of these some remain on the same side of the cord and are thus associational in type, whilst others cross to the opposite side of the cord and are commissural.

In addition to the foregoing types of cell-bodies found in the grey matter of the spinal cord a large number of myelinated collateral branches enter it from the tracts of the spinal cord, as well as both myelinated and non-myelinated axons from the dorsal spinal nerve roots. These establish synaptic contact with the neurons of the grey matter itself, so that the alternative channels provided for branching nerve impulse within the several segments of the spinal cord are very nu-

merous. After entering the grey matter the myelinated axons tend to lose their medullary sheath, and it is this scarcity of myelin which confers upon the grey matter its characteristic naked eye appearance.

The Cell Columns of the Grey Matter of the Spinal Cord. Although the cell bodies of the neurons found within the grey matter of the spinal cord are scattered throughout its whole substance, they tend nevertheless to be generally arranged in columns of cells, and this arrangement is of some clinical importance. The general arrangement of these spinal cord cell columns is as follows.

The *somatic effector cells* occupy the ventral grey column, and subdivide themselves into lesser groups according to the groups of muscles to be innervated.

The *splanchnic effector cells* occupy the lateral grey column of the spinal cord, particularly in the thoracic and upper lumbar regions where they form the intermedio-lateral cell column. They form part of the effector apparatus of the vertebral sympathetic system.

The *cells of the dorsal grey column* tend to be scattered and, except for the dorsal nucleus of Clarke, are not arranged in definite columns, as are those of the ventral and lateral horns.

The Somatic Effector Cells of the Ventral Grey Column. The cells of the ventral grey column of the spinal cord are large in structure and effector in function. Their axons pass out through the ventral roots of the spinal nerves and are distributed to the voluntary somatic muscles. The cells are, therefore, particularly numerous in the cervical and lumbar enlargements of the spinal cord on account of the associations of these areas with the musculature of the limbs.

On the medial side of the ventral grey column of the spinal cord the cells arrange themselves in two columns, one behind the other. They are, therefore, differentiated as the ventro-median and the dorso-median cell columns. The *ventro-median cell column* extends through practically the whole length of the spinal cord, being absent in only the fifth lumbar

FIG. 651.—SCHEMATIC REPRESENTATION OF THE SHAPE AND POSITION OF THE VARIOUS FASCICULI OR CONDUCTION PATHS OF THE SPINAL CORD AND THE GROUPING AND SIGNIFICANCE OF THE CELL-BODIES OF THE GRAY SUBSTANCE.

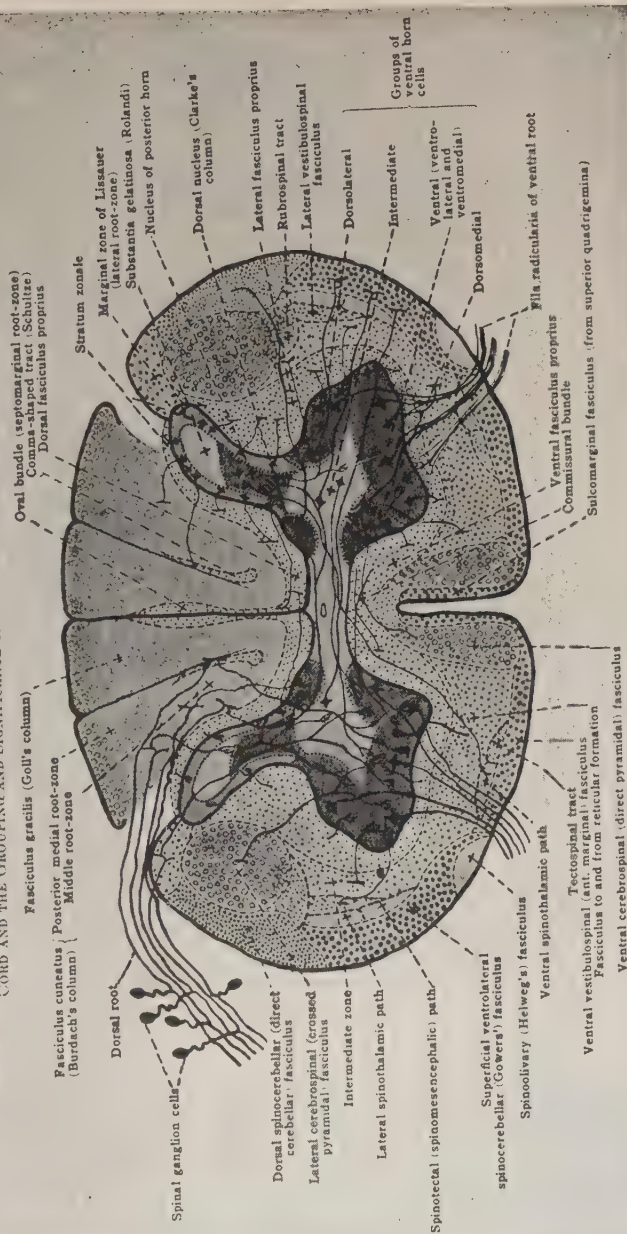


FIG. 33.—Schematic representation of the shape and position of the various fasciculi or conduction paths of the spinal cord and the grouping and significance of the cell bodies of the gray substance. (From: Morris, "Human Anatomy.")

and first sacral segments. The *dorso-median cell column* is found chiefly in the thoracic region, with smaller extensions in the cervical and first lumbar segments. It is generally believed that the axons of both these groups of cells are distributed to the trunk musculature.

In the cervical and lumbar enlargements other cell columns are found on the lateral side of the ventral grey column of the cord which preside over the limb musculature. These are differentiated, from their position as the ventro-lateral and the dorso-lateral cell columns. The *ventro-lateral cell column* is found in the fourth to the eighth cervical segments (upper limb) and the second lumbar to the second sacral segments (lower limb). The *dorso-lateral cell column* is found in the lower five cervical segments (upper limb) and the lower four lumbar and upper three sacral segments (lower limb). The cervical and lumbar enlargement of the spinal cord also contain additional groups of effector cells, thus in the eighth cervical, first thoracic, and first three sacral segments, an additional cell column is found lying behind the dorso-lateral cell column, and in the second lumbar to the second sacral segments a more independent group of cells lies in the centre of the ventral grey column of the cord. These two groups are sometimes termed the *retro-dorso-lateral* and the *central*, respectively.

The Splanchnic Effector Celis of the Lateral Grey Column. The splanchnic effector cells of the lateral grey column are the pre-ganglionic cells of the vertebral sympathetic system. The cell bodies are small and occupy a distinctive area in the lateral column of the grey matter of the spinal cord in all the thoracic and upper lumbar segments. The cell column is, therefore, sometimes termed the *intermedio-lateral* cell column. The axons of these cells pass out through the ventral roots of the spinal nerves and the white rami communicantes into the vertebral sympathetic trunk, through which they are distributed to the muscle of viscera, heart, glands, etc.

A similar group of cells is found in the third and fourth

sacral segments which belong to the sacral outflow of the parasympathetic system.

The Cells of the Dorsal Grey Column. Within the dorsal grey column of the spinal cord the cells do not tend to arrange themselves in columns, as in the ventral and lateral columns, but are more indiscriminately scattered throughout. The majority of these cells are the cell stations for those axons which form the fasciculi proprii of the spinal cord, and are thus intersegmental in character; they are chiefly concerned with the reception and distribution of nerve impulses entering the cord through the dorsal spinal nerve roots.

On the medial side of the base of the dorsal grey column there is a group of larger cells found in the eighth cervical, all the thoracic, and first two or three lumbar segments, known as the *dorsal nucleus of Clarke*. The cell-bodies are oval or pyriform in shape with several dendrons by which they effect synaptic contact with incoming proprioceptive neurons through the dorsal spinal nerve roots. The axons of the dorsal nucleus of Clarke pass outwards to the periphery of the spinal cord within the lateral funiculus where they turn upwards as the spino-cerebellar tracts.

Spinal Cord Reflex Neuronic Mechanism. A study of both the white tracts and the cell stations within the grey matter shows that many neuronic reflex arcs are provided within the spinal cord, and that these are of considerable importance in both health and disease. The spinal cord links in these neuronic arcs are clearly furnished by those neurons which have their cell stations within the dorsal grey column.

Within the spinal cord there are found two chief types of neuronic arcs, the intra-segmental and the inter-segmental, each subdivided into associational and commissural.

If the spinal cord connector neuron be between receptors and effectors of one segment only, the reflex action is limited to the segment in which it occurs and the arc is *intra-segmental*. If it pass between a receptor and an effector of the same side it is an associational intra-segmental reflex. If, however, the spinal cord connector neuron crosses over to the

opposite side of the same segment, it is a commissural intra-segmental reflex.

Much more frequently, however, the connector neuron extends over several segments of the spinal cord, giving off collaterals to each one of the segments it passes. The reflex is then *intersegmental* in character, and may be associational or commissural as before. It consequently follows that receptor impulses entering any one segment of the spinal cord through a dorsal spinal nerve root may reach the effector elements of that segment by way of an intra-segmental arc, or may reach other segments of the spinal cord by way of the inter-segmental arcs, and, in the latter case, may do so by one or other of two routes; (1) by way of the ascending or descending branches of the dorsal root axons; or (2) through the medium of the internuncial neurons of the fasciculi proprii.

The *scratch reflex of the dog*, worked out by Sherrington so far back as 1906, is a typical example of a spinal cord reflex. If the spinal cord be transected in the cervical region, and some time thereafter, the skin covering the dorsal thoracic region be stimulated by lightly pulling on the hair, a receptor stimulus is transferred to the segment concerned, this in its turn stimulates a long descending associational neuron, which in its turn affects the final common effector neuron of a limb muscle, and the hind-limb of the side commences a series of rhythmic scratching movements.

The final common effector neuron thus reacts to stimuli from many sources, and the human spinal cord affords many examples of its reflex activities impaired by diseases.

The medulla oblongata, and to a lesser extent, the pons, are in man, even more important centres of reflex activities than the spinal cord. Among the *medullary reflexes* may be mentioned the vaso-motor, the respiratory, the cardio-inhibitory, the involuntary movements of the eyelids for the moistening of the conjunctiva and cornea, the light reflex upon the sphincter pupillæ muscle, and so on. Further, the mechanism and construction of the nervous system is such that many skilled movements, which have origi-

nally to be learned or acquired, eventually become more or less entirely reflex or involuntary. Amongst such movements may be mentioned walking, bicycle riding, dancing and the like. In learning such movements, the individual must *establish his reflexes*.

A knowledge of the spinal cord reflexes is of great clinical importance, inasmuch as many of them are altered, lost, or impaired by disease, and may even be exaggerated, but their description does not involve more structural detail than as already described.

CHAPTER XII

THE NAKED EYE ANATOMY OF THE MEDULLA OBLONGATA, PONS, AND FOURTH VENTRICLE

Form and Position of the Medulla Oblongata. At its upper end the spinal cord expands slightly and passes without any perceptible line of demarcation into the myelencephalon or medulla oblongata. The latter is, therefore, an upward or cranial continuation of the spinal cord, and forms part of the brain stem, or connecting link between the spinal cord and brain.

The medulla oblongata is about 2.5 cm. in length, and may be regarded as extending from the level of the first cervical nerve, from which it is separated by the decussation of the pyramids, opposite the occipital foramen magnum to the lower or medullary border of the pons. Between these limits the medulla rests by its ventral surface on the clivus of the occipital bone, and its dorsal surface is sunk in the vallecule of the cerebellum. As traced from the spinal cord to the pons, the medulla expands in the transverse, and to a less extent in the sagittal diameter.

Natural Subdivisions of the Medulla Oblongata. The medulla, like the spinal cord, is a bilateral structure, and is divided into two equal halves by ventral and dorsal median fissures. Each lateral half is still further subdivided into three areas by means of ventro-lateral and dorso-lateral sulci.

The *ventral median fissure* of the medulla is a continuation of, and corresponds to, the similarly named fissure of the spinal cord, the two being interrupted, however, at the junction of the medulla and cord by the decussation of the pyramids. At the junction of the medulla and pons, the fissure ends in a triangular depression, the *foramen caecum*. In the medulla

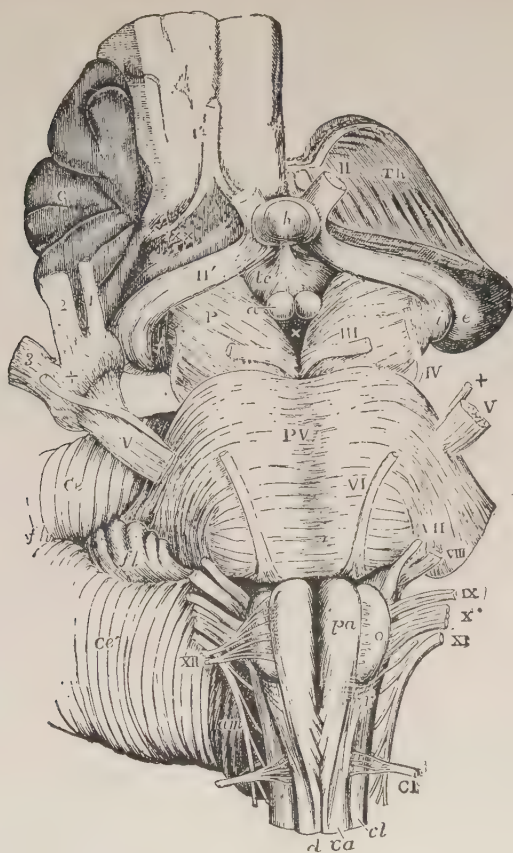


FIG. 34.—View from before of modulla oblongata, pons Varolii, crura cerebri, and other central portions of the encephalon. (Allen Thomson.) Natural size. On right side the convolutions of the central lobe or island of Reil have been left, with a small part of the anterior cerebral convolutions; on left side these have been removed by an incision carried between the thalamus opticus and the cerebral hemisphere. I', olfactory tract cut short and lying in its groove; II, left optic nerve in front of the commissure; II', right optic tract; Th, cut surface of the left thalamus opticus; C, central lobe or island of Reil; Sy, fissure of Sylvius; X, X, anterior perforated space; e, external, i, internal corpus geniculatum; h, hypophysis cerebri or pituitary body; lc, tuber cinereum with infundibulum; a, one of the corpora albicantia; P, cerebral peduncle or crus; III, close to left oculomotor nerve; X, posterior perforated space. The following letters and numbers refer to parts in connection with the medulla oblongata and pons; PV, pons Varolii; V, greater root of 5th nerve; +, lesser or motor root; VI, 6th nerve; VII, facial; VIII, auditory nerve; IX, glossopharyngeal; X, pneumogastric; XI, spinal accessory; XII, hypoglossal; CI, suboccipital or 1st cervical nerve; pa, pyramid; o, olive; d, ventral median fissure of spinal cord, above which the decussation of the pyramids is represented; ca, ventral column of cord; r, lateral tract of bulb continuous with cl, the lateral column of the spinal cord. (From: Luciani, "Human Physiology.")

the ventral median fissure is sometimes rendered somewhat shallow by the emergence from it of some arch-like fibres or strands termed *ventral external arcuate fibres*.

The *dorsal median fissure* is present only in the lower half of the medulla, and is directly continuous with the dorsal median sulcus of the spinal cord. When traced upwards the fissure becomes shallower and opens out into the rhomboid fossa of the fourth ventricle. The lower half of the medulla, containing as it does, the central canal, is thus *closed*, whilst the upper half, where that canal comes to the dorsal surface as the fourth ventricle, is termed the *open* part of the medulla.

The *ventro-lateral sulcus* is a continuation of the similarly named sulcus in the spinal cord. It forms the natural line of demarcation between the ventral and lateral areas of the medulla, and from its depth emerge the root fasciculi of the hypoglossal nerve.

The *dorso-lateral sulcus* is a continuation of the similarly named sulcus in the spinal cord. It forms the natural line of demarcation between the lateral and dorsal areas of the medulla, and along it are the receptor and effector rootlets of the vago-glosso-pharyngeal nerve.

Areas of the Medulla Oblongata. By means of the foregoing fissures and sulci each bilateral half of the medulla is divided into three areas analagous to the three white funiculi of the spinal cord. In fact, the three areas of the medulla would appear to be direct continuations of those funiculi, but this is not really the case, because the nerve fibres of the spinal cord funiculi undergo some rearrangement as they pass through the medulla.

The Ventral Area of the Medulla Oblongata. The ventral area of the medulla lies between the ventral median fissure and the ventro-lateral sulcus. It assumes the form of a prominent white mass, termed the *pyramid*, which has the false appearance of being continuous with the ventral white funiculus of the spinal cord. It is formed by the medullated axons of the cortico-spinal or pyramidal tracts. At the junction of the medulla and spinal cord most of the axons of the pyramid

undergo a complete decussation, the *decussation of the pyramids*, which crosses the middle line in the form of large obliquely interdigitating bundles which fill up and almost obliterate the ventral median fissure. As the result of this decussation the axons of the pyramid take up a position in the lateral funiculus of the spinal cord and are there known as the lateral or crossed cortico-spinal tract, whilst the undecussated axons remain on the same side, enter the ventral white funiculus of the spinal cord and there form the anterior or direct cortico-spinal tract.

The Lateral Area of the Medulla Oblongata. The lateral area of the medulla lies between the ventro-lateral and dorso-lateral sulci, or, in other words, between the root origins of the hypoglossal and vago-glosso-pharyngeal nerves. The appearances presented by the lateral area of the medulla differ in the lower and upper portions.

In its *lower half* the lateral area of the medulla appears as a direct continuation of the lateral white funiculus of the spinal cord, but as a matter of fact some striking changes have occurred, and the appearances of continuity are misleading. In the lateral area of the medulla the lateral or crossed cortico-spinal tract of the lateral area of the cord is no longer present, as it has passed forwards into the pyramid, and the dorsal spino-cerebellar tract of Flechsig has similarly passed backwards into the restiform body. What remains of the lateral white funiculus of the spinal cord is continued upwards into the lower half of the lateral area of the medulla. In the *upper half* of the lateral area of the medulla the surface markings are quite altered by the appearance of a smooth, oval projection, termed the *olive*, produced by a subjacent medullary nucleus which has no prototype in the spinal cord, and the surface of which is often seen to be crossed by some fine transverse strands known as the *ventral external arcuate fibres*.

The Dorsal Area of the Medulla Oblongata. The dorsal area of the medulla lies between the dorso-lateral sulcus on the one hand, and the dorsal median fissure and the lateral margin of the fourth ventricle on the other. Just as in the

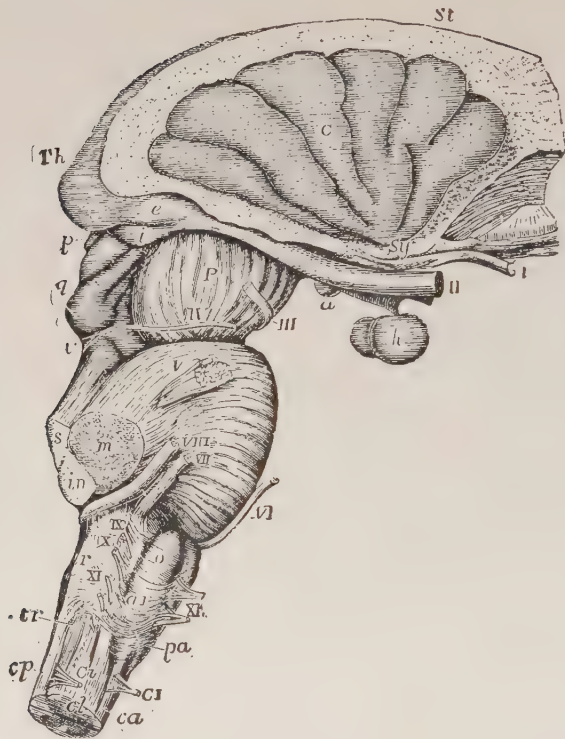


FIG. 35.—View of medulla oblongata, pons Varolii, crura cerebri, and central parts of encephalon from right side. (Allen Thomson.) The corpus striatum and thalamus have been preserved in connection with the central lobe and crura cerebri, while the remainder of the cerebrum has been removed. *St*, upper surface of corpus striatum; *Th*, back part of thalamus (pulvinar); *C*, placed on the middle of the five or six convolutions constituting the central lobe or island of Reil, the cerebral substance being removed from its circumference; *Sy*, fissure of Sylvius, from which these convolutions radiate, and in which are seen the white striae of the olfactory tract; *I*, the olfactory tract divided and hanging down from the groove in the convolution which lodges it; *II*, optic nerves a little way in front of the chiasma; *a*, right corpus albicans with tuber cinereum and infundibulum in front of it; *h*, hypophysis or pituitary body; *e*, external, *i*, internal corpus geniculatum at back part of optic tract; *P*, peduncle or crus of cerebrum; *III*, right oculo-motor nerve; *p*, pineal gland; *q*, corpora quadrigemina; *IV*, trochlear nerve rising from *v*, valve of Vieussens. The following numbers and letters refer chiefly to parts in connection with medulla oblongata and pons: *V*, on pons Varolii above right nervus trigeminus; *s*, superior, *m*, middle, *in*, inferior peduncle of cerebellum cut short; *VI*, 6th nerve; *VII*, facial nerve; *VIII*, auditory nerve; *IX*, glosso-pharyngeal nerve; *X*, opposite cut end of pneumogastric nerve; *XI*, uppermost fibres of spinal accessory nerve; *XII*, hypoglossal nerve; *pa*, pyramid; *o*, olive; *ar*, arciform fibres; *r*, restiform body; *tr*, tubercle of Rolando; *cg*, ventral; *cn*, dorsal; *cl*, lateral columns of spinal cord; *CI*, *Ci*, ventral and dorsal roots of 1st cervical nerve. (From: Luciani, "Human Physiology.")

lateral area of the medulla the surface appearances here differ in the upper and lower parts.

In the *lower part* of the dorsal area of the medulla there may be seen three longitudinal elevations which are, in order from the dorso-lateral sulcus to the dorsal median fissure, the tuberculum cinereum, the cuneate funiculus, and the gracile funiculus.

The *tuberculum cinereum* has no counterpart on the surface of the spinal cord. Its appearance on the surface of the medulla is due to the fact that the substantia gelatinosa forces its way to the surface and thus forms a bulging eminence. Over this is spread a thin sheet of white matter, which is the spinal tract of the trigeminal nerve.

The *cuneate funiculus* is the medullary equivalent of the cuneate tract of the spinal cord, which here enlarges and so forms the cuneate tubercle.

The *gracile funiculus* is the medullary equivalent of the gracile tract of the spinal cord and terminates above in a club-like extremity, the *clava*. Both the cuneate and gracile funiculi are due to the presence, within the medulla, of two elongated collections of grey matter, termed the *gracile* and *cuneate nuclei*, around the cells of which the axons of the gracile and cuneate tracts of the cord terminate by synaptic arborisation. Between the two clavae the central canal of the spinal cord opens out into the floor of the fourth ventricle.

In the *upper half* of the dorsal area of the medulla the three elevations of the lower half are replaced by the *restiform body*, which has no structural continuity with them. The restiform body is a large, prominent, rope-like strand, which runs along the lateral border of the fourth ventricle and then turns backwards or dorsally into the cerebellum. It contains axons which serve to link the medulla and spinal cord with the cerebellum, and even with the naked eye some of its constituent elements, such as the ventral external arcuate fibres and the dorsal spino-cerebellar tract, can be seen entering it.

Just where the restiform body begins to turn dorsally into the cerebellum, it can be seen to be partly encircled by an

elongated transversely placed elevation, formed by the ventral and dorsal cochlear nerve nuclei. This ridge is continuous laterally with the cochlear nerve, and medially with the acoustic medullary striae, which can sometimes be seen crossing the floor of the fourth ventricle.

Nerve Roots. From the surface of the medulla oblongata several cerebral nerves make their appearance. Along the dorso-lateral sulcus, in line with the entering nerve roots of the dorsal spinal nerves, are the rootlets of the accessory, vagus, and glossopharyngeal nerves, the first of which is effector in function, and the last two, mixed in type. From the ventro-lateral sulcus, in line with the ventral spinal nerve roots are the emerging filaments of the effector hypoglossal nerve. At the upper border of the medulla, between it and the pons the abducent, facial, and acoustic (cochlear and vestibular) nerves make their superficial appearance, in that order from the middle line.

The Pons Varolii. The pons is that part of the brain stem which intervenes between the medulla and the mid-brain, and lies ventral to the cerebellum. It assumes the form of a broad, transversely striated mass, sharply marked off from both the medulla and the peduncles of the cerebrum, and is convex in both the sagittal and transverse diameters. It rests upon the clivus and extends upwards as far as the dorsum sellae. Laterally, it becomes uninterruptedly continuous with the middle cerebellar peduncle (brachium pontis), the artificial line of separation being the superficial origin of the trigeminal nerve.

The *upper* or *mesencephalic border* of the pons bounds the interpeduncular fossa and crosses the peduncles of the cerebrum. It is, therefore, closely related to the posterior perforated substance of the interpeduncular fossa, the oculomotor nerves, and the peduncles of the cerebrum.

The *lower* or *medullary border* of the pons overhangs the medulla, and is closely related to the foramen caecum, and the superficial origins of the nerves previously mentioned.

The *ventral surface of the pons* is grooved by the basilar

artery, on either side of which the surface projects forwards, these convexities being produced by the passage through the pons of the effector or pyramidal longitudinal fibres, whilst the transverse striations are produced by the transverse fibres of the pons.

The *dorsal surface of the pons* is bounded, on either side, by the superior cerebellar peduncle (brachium conjunctivum) and takes part in the formation of the floor of the fourth ventricle.

The Fourth Ventricle. The fourth ventricle is that part of the original cavity of the neural tube which comes to the surface on the dorsal sides of the pons and medulla, between them and the cerebellum, and is, therefore, a development of the rhombencephalon. It is directly continuous with the central canal of the spinal cord and the cerebral aqueduct of Sylvius, and by means of the latter it establishes continuity with the third ventricle.

The fourth ventricle presents for examination a roof and a floor. Of these the former is very thin, and is intimately connected with the cerebellum, whilst the latter is lozenge-shaped or rhomboidal in outline, and is hence usually referred to as the rhomboid fossa.

The Rhomboid Fossa of the Fourth Ventricle. The rhomboid fossa is the slightly depressed area formed by the pons and medulla, and is quite arbitrarily divided into three parts, superior, intermediate, and inferior. It is covered throughout, as though by a carpet, by a continuation of the grey matter found around the central canal of the spinal cord.

The *inferior part* of the rhomboid fossa is triangular in outline with the apex caudally, and is formed by the medulla oblongata. It is bounded laterally by the restiform bodies, whilst its apex, termed the *calamus scriptorius*, is wedged in between the two clavae, at which point the cavity of the ventricle becomes continuous with that of the central canal of the spinal cord. To the margins of this area is attached the tela chorioidea of the fourth ventricle.

The *superior part* of the rhomboid fossa, formed by the

pons, is also triangular in outline with the apex directed upwards. It is bounded laterally by the superior cerebellar peduncles (brachia conjunctiva), and is roofed in by the anterior medullary velum.

Between the superior and inferior parts of the rhomboid fossa is an intermediate area, the *intermediate part*, where

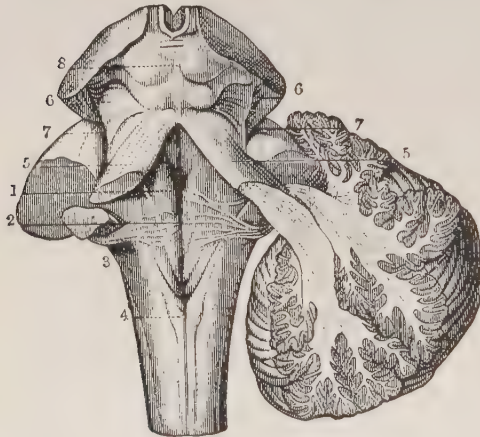


FIG. 36.—The three pairs of cerebellar peduncles. (Sappey, after Hirschfeld and Leveillé.) On left side the three cerebellar peduncles have been cut short; on right side the hemisphere has been cut obliquely to show its connection with the superior and inferior peduncles. 1, median groove of fourth ventricle; 2, same groove at the place where the auditory striæ emerge from it to cross the floor of the ventricle; 3, inferior peduncle or restiform body; 4, funiculus gracilis; 5, superior peduncle—on right side the dissection shows the superior and inferior peduncles crossing each other as they pass into the white centre of the cerebellum; 6, fillet at side of the crura cerebri; 7, lateral grooves of crura cerebri; 8, corpora quadrigemina. (From: Luciani, "Human Physiology.")

the fossa attains its widest diameter and extends laterally on to the restiform body as the *lateral recess*.

Structures Visible in the Floor of the Fourth Ventricle. The floor of the fourth ventricle, or the rhomboid fossa, is divided into two almost symmetrical halves by the *median sulcus*, on either side of which and extending throughout the whole length of the fossa is a ridge, the *medial eminence*, which is bounded laterally by a slight variable *limiting sulcus*, and presents, in the intermediate part of the rhomboid fossa,

a broader, well-marked elongated elevation, the *facial colliculus*, under cover of which the axons of the facial nerve bend round the abducent nerve nucleus. In the upper part of the limiting sulcus, extending from the superior fovea to the cerebral aqueduct is a shallow groove, usually faint blue in colour, the *locus cæruleus*, deep to which lies the substantia

ferruginea, composed of some deeply pigmented cells. When traced downwards from the locus cæruleus, the limiting sulcus broadens out near the facial colliculus to form the triangular area, termed the *superior fovea*. Below the superior fovea the limiting sulcus is crossed by the variably developed *medullary striae*, which are medial prolongations from the cochlear nerve nuclei.

In the inferior part of the rhomboid fossa, and below the medullary striae, the limiting sulcus again broadens out to form an inverted V-shaped area, the *inferior fovea*, the diverging limbs of which subdivide this part of the rhomboid fossa into three small areas, medial, intermediate, and lateral.

The medial area is termed the *hypoglossal nerve triangle*, because subjacent to it is the origin of the hypoglossal nerve. The intermediate area, between the two diverging limbs of the inferior fovea, is named the *ala cinerea* or the *triangle of the vagus nerve*—the former name indicates the colouration of the area, the latter that it is the seat of the nucleus of the vagus nerve. Lateral to the lateral limb of the inferior fovea, between it and the restiform body, is the *area acustica*, or better, the *vestibular area*, subjacent to which lie the nuclei of the vestibular nerve. This vestibular area is not restricted to the inferior part of the rhomboid fossa, but extends up into the lateral angle of the intermediate part, in which it ends as the so-called acoustic tubercle, which is usually feebly developed in man, and is crossed by the medullary striae.

The foregoing description of the structures seen in the floor of the fourth ventricle has been based upon the limiting sulcus, because that sulcus indicates the line of separation between the parts developed from the basal plate on the medial side of the sulcus, and the alar plate on the lateral side of the sulcus. The former is, of course, effector in function, and the latter receptor.

The Roof of the Fourth Ventricle. The roof of the fourth ventricle should be studied in sagittal section, as well as by dissection from the dorsal side. With the parts *in situ*, it is concealed by the cerebellum, and is formed in the superior

part of the rhomboid fossa by the anterior medullary velum; in the intermediate part, by the posterior medullary velum; and in the inferior part by the tela chorioidea lined by the ependymal epithelium.

The *anterior medullary velum* is a thin sheet of white matter continuous with the white medullary substance of the cerebellum, through which some of the axons of the indirect or ventral spino-cerebellar tract of Gowers enter the cerebellum. It is spread out between the two converging superior cerebellar peduncles, and thus roofs in the upper part of the fourth ventricle. Resting upon its dorsal surface are a few cross strands of grey matter belonging to the superior vermis and sometimes termed the *lingula*. Issuing from the anterior medullary velum, close to the inferior colliculus, is the fourth or trochlear nerve.

The *posterior medullary velum* is a thin, narrow, almost translucent sheet of white matter, which issues from the white medullary centre of the cerebellum, turns ventro-caudally around the nodule of the vermis, to roof in the intermediate part of the fourth ventricle. It ends caudally in a free, slightly thickened and crescentic edge. As the two medullary vela emerge from the medullary centre of the cerebellum they diverge from each other at an acute angle, and hence the roof of the fourth ventricle is somewhat tent-shaped. The angle so formed is termed the *fastigium*.

In its inferior part the fourth ventricle is roofed in by the extremely thin *tela chorioidea* lined internally by the ependymal epithelium. The former is attached to the lower free edge of the posterior medullary velum and the flocculus, and extends thence to the margins of the fourth ventricle. It is really a part of the pia matter and is rich in blood vessels. From it vascular tufts project into the cavity of the ventricle, but are separated therefrom by the lining ependymal epithelium. The vascular tufts form the chorioid plexus of the ventricle. The ependymal epithelium consists only of a single layer of cells and is continuous with that lining all the other walls of the ventricle. In this particular situation it comes

into contact with the pia mater, hence the extreme thinness of this part of the roof of the fourth ventricle.

In the embryo the tela chorioidea is an absolutely continuous structure, but it soon becomes perforated in three places. Of these one is the single median aperture of the fourth ventricle, or the *foramen of Magendie*, and lies opposite the obex. The two remaining apertures, the *lateral apertures* of the fourth ventricle, correspond approximately in position to the apices of the lateral recesses, and are closely related to the roots of the vago-glosso-pharyngeal nerves. It is by means of these three apertures that the cerebrospinal fluid secreted by the vessels of the chorioid plexuses of the ventricles is removed to the exterior of the brain. Should the apertures not form, or should they subsequently become occluded as a result of disease, hydrocephalus with cerebral pressure may result.

CHAPTER XIII

THE EVOLUTIONARY HISTORY OF THE MEDULLA OBLONGATA

Medulla a Cerebral Continuation of the Spinal Cord. The medulla oblongata is an upward or cerebral continuation of the spinal cord, and forms a transitional structure between the *cord* or *myelon*, and the later evolutionary product, the *brain* or *encephalon*, hence the name often given to the medulla of *myelencephalon*. Like the spinal cord the medulla is a segmented structure, but the segmentation has become so modified by alterations and additions, as to make the study of the medulla, or the recognition of its segmentation, an extremely difficult task.

Early Modifications at the Head End. The oldest part of the head is the mouth, the primitive function of which was the capture, and introduction into the body, of food, hence the mouth became the point of approach to the food supply, and thus determined the direction of locomotion. With the acquisition of the power of approaching the food, a property not possessed by stationary organisms like the anemone, primitive gustatory, olfactory, and tactile organs became developed at the head end, and established neuronic connection with the cephalic end of the spinal cord, which thus became expanded into the form of a primitive end-brain or medulla. In due course all these delicate sensory organs, as well as the medullary portion of the neuraxis with which they established connection, became protected by osseous and other growths, such as teeth, so that the head end, or mouth containing portion, was still further specialised and transformed into a mechanism for offence and defence, as is well instanced in the shark.

The Further Influence of Gills. With the advent of the gill-breathing fish, the mouth became implicated in the func-

tion of respiration, over which the medulla had again to take neuronie control. The addition of this splanchnic function to the medulla still further concealed its original segmental nature, because the gill-bearing segments are derived from branchiomeres, and those of the body from metameres, and thus two different types of segmentation were impressed upon the central neuraxis, the latter prevailing in the spinal cord, and the former in the medulla. As soon as the medulla assumed control over respiration, as in these gill-bearing animal forms, it became immediately necessary for it to exercise a similar control over the blood circulation, because the function of the former was to aerate the latter, and the central neuronie machinery of both had to be co-ordinated into a working whole. Hence in all gill-breathing animal forms the heart is situated in close proximity to the gills, and the functions of the medulla become considerably extended, and now assume control over, and regulation of, all those receptors and effectors which co-operate in the process of the aeration of the blood, and its circulation. The visceral or splanchnic functions of the medulla are thus still further extended and include both the respiratory and circulatory organs. This early property of the medulla has been preserved in all subsequent vertebrates, notwithstanding the later additions to the neuraxis of additional "brains" beyond the medulla, and the substitution of lungs for gills, hence the medulla differs from the spinal cord, not only in its mode of segmentation but also in its functions. The former is primarily branchiomic in segmentation and visceral in function. The latter is metameric in segmentation and somatic in function.

"The primitive relations of the mouth as an aperture for the intake of food and for aerating the blood have determined a close association between the cardio-vascular, alimentary, and respiratory systems. This relationship is reflected in the influence which the medulla oblongata has continued to exert over these three systems. The control of deglutition and gastro-intestinal activities, respiration, and cardiac action, has come to be an autonomy vested in the medulla oblongata.

From this fact the organ takes its chief importance in the regulation of life, and has gained its reputation as the 'vital node.' " (Tilney and Riley.)

Consequent Alterations in the Grey Matter. Now it is obviously impossible for the medulla, or indeed any other portion of the neuraxis, to assume such greatly extended neuronic activity and control, without a corresponding increment in the amount of the centrally situated cell stations, that is, of the grey matter. The metamerically segmented and somatic spinal cord type, with the grey matter inside, and the white matter outside, clearly allows of no extension of grey matter. Its amount must always be circumscribed and limited. The branchiomic medulla, with its greatly extended visceral or splanchnic functions, urgently needs an extension in the amount of its grey matter, and this is brought about by a failure of fusion of the alar laminæ in the medullary region. The result of this failure is that the central canal of the spinal cord, around which the grey matter is placed, is brought on to the dorsal surface as the fourth ventricle, and the grey matter becomes spread out over it. Once the grey matter has been brought to the exterior, no further difficulty is experienced in augmenting it in amount, and adapting it to the requirements of the animal.

It is thus obvious that the autonomous control which the medulla has come to assume over the vital functions of life, has necessitated its subsequent development on the lines of its active substance, the grey matter. "The result of this development is seen in the enlargement of the medulla oblongata as a whole when compared with the spinal cord. It is further evidenced by the appearance of the fourth ventricle, which has permitted the expansion of the central grey matter. . . . The central grey matter in this way acquires greater proportions than in the spinal cord. In some of the fish, the fourth ventricle is not only an extensive cavity, but also presents upon its floor a series of longitudinal columns of grey matter." (Tilney and Riley.) These grey longitudinal columns in the fourth ventricle represent the cell sta-

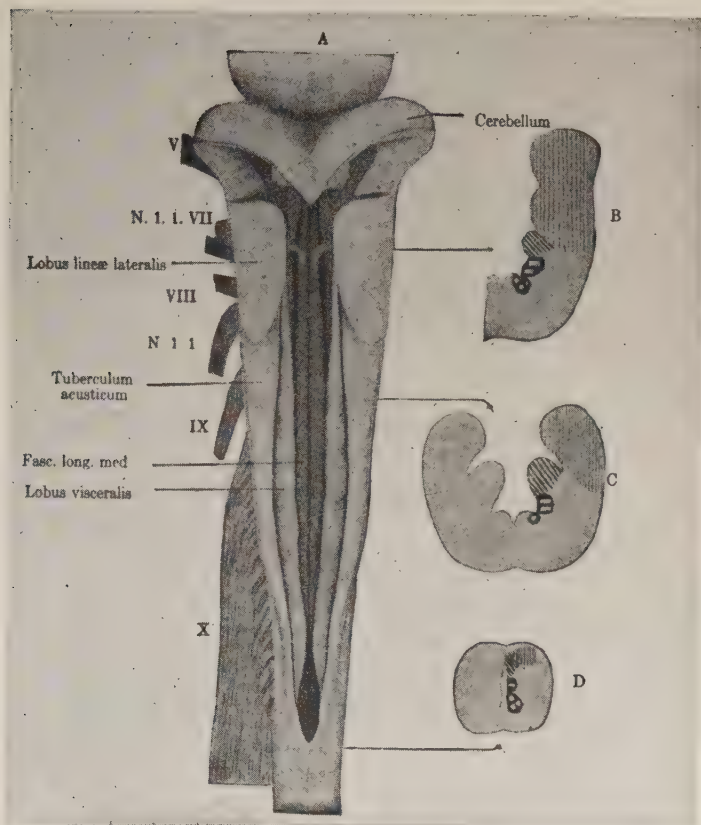


FIG. 37.—The medulla oblongata and cerebellum of the lake sturgeon (*Acipenser rubicundus*) to show the longitudinal columns which have been differentiated in correlation with the peripheral functional systems. A is a dorsal view with the membranous roof of the fourth ventricle removed to show the longitudinal columns within the ventricle. B, C, and D are sketches of cross-sections at the levels indicated in which the four functional columns are diagrammatically shaded, the somatic motor by white circle, the visceral motor by white rectangles, the visceral sensory by oblique cross-hatching, and the somatic sensory by vertical cross-hatching. The Roman numerals refer to the cranial nerves. (From Johnston's *Nervous System of Vertebrates*.)

tions which preside over the various activities of the medulla, thus the visceral lobe controls respiration and cardiac activity, to which is subsequently added the gustatory sense; the lobe of the lateral line presides over the balancing mechanisms, whilst the somatic lobe acts in the direction of motion and the regulation of bodily balance.

It is thus clear that, while the medulla is undoubtedly a prolongation of the spinal cord, the numerous functions which it has been called upon to control have necessitated a more complex form of structure, the chief of which is to be sought in the grey matter and its extension. It is these facts which explain the apparently totally different and, at first, somewhat perplexing structure of the medulla, as compared with the spinal cord.

The complexity of medullary construction is still further increased by the subsequent evolutionary addition of cerebral hemispheres, and the transference thereto of functions previously undertaken by earlier portions of the neuraxis, but the basic evolutionary features of the medulla, which explain much of its apparently complex structure, are that "the medulla oblongata, from the beginning of vertebrate organisation, has comprised a series of segments in which was vested the autonomous control of cardio-vascular, respiratory, and gastro-intestinal activities. To these offices have been added the regulation of body movement in the interests of equilibrium and a special mechanism which made the auditory function possible. The interpretation of the anatomy of the medulla will be aided by holding these facts in the foreground. The explanation of the modifications to which this organ has been subject in man must be sought in the progressive adaptations developed in consequence of special adjustments to terrestrial life." (Tilney and Riley.)

CHAPTER XIV

THE MINUTE STRUCTURE OF THE MEDULLA OBLONGATA

Structural Differences Between the Spinal Cord and the Medulla. Although the medulla oblongata is an upward or cerebral continuation of the spinal cord, and like the cord is a segmented structure, the two parts differ, for reasons set forth in the last chapter, so profoundly as to make the study of the minute structure of the medulla a difficult and complex problem.

In the medulla oblongata the various *white tracts*, which occupy such definite positions in the spinal cord, either come to an end, or change their positions prior to continuing their upward course, or pass completely out of the medulla to enter the cerebellum. In any case the differentiation between white and grey matter, which is so conspicuous a feature of the cord, is completely lost in the medulla.

As explained in the last chapter, the grey matter is, in the medulla, forced to the surface, and elsewhere becomes so commingled with the white matter as to cause all differentiation between grey and white matter to become lost. It consequently follows that the grey matter of the medulla oblongata is not arranged in compact columns, as in the spinal cord, but becomes broken up, partly by the decussations of the effector pyramids and the receptor fillets, into a series of separated and isolated masses of grey matter, termed *discrete nuclei*. From the basal or effector lamina of the rhombencephalon there are thus developed, not one compact mass of grey matter, like the ventral grey columns of the cord, but three distinct broken columns of grey effector nuclei, termed respectively, the medial somatic, lateral somatic, and splanchnic

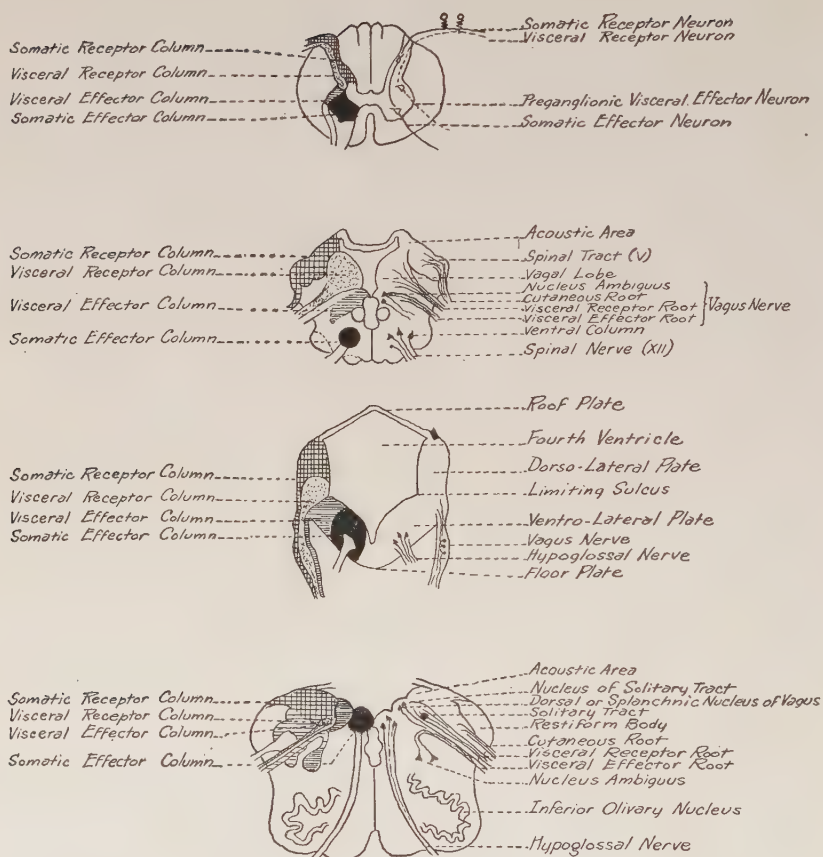


FIG. 38.—Four drawings, after Herrick, to illustrate changes in position of the visceral and somatic receptor and effector columns in the medulla consequent on the failure of fusion of the alar laminae in the medullary region. See pages 81, 172, 175.

First figure.—Diagrammatic transverse section through the human spinal cord.

Second figure.—Diagrammatic transverse section through the medulla of a bony fish at the level of the vagus nerve.

Third figure.—Diagrammatic transverse section through the medulla of a human embryo of 10.2 m.m. Fifth week. At the level of the vagus nerve.

Fourth figure.—Diagrammatic transverse section through the adult human medulla.

columns, which correspond, in the medulla, to the ventral and lateral grey columns of the cord.

Within the *alar* or *receptor lamina* of the rhombencephalon are developed the receptive and discrete nuclei of various receptor nerves, which thus correspond, in the medulla, to the dorsal grey columns of the cord.

Besides these two groups of grey matter, basal and alar, which are the homologues in the medulla of the ventral and dorsal grey columns of the spinal cord, there are also added in the medulla, and chiefly in connection with the receptor alar lamina, special masses of grey matter, or discrete nuclei, which have no equivalents in the spinal cord. These serve as links in the complex chain of nerve elements and connect the medulla to other parts of the nervous system, and to the great co-ordinating mechanism of the cerebellum.

These three groups of discrete nuclei within the medulla, together with their homologues in the spinal cord, if any, may be summarised as follows:

SPINAL CORD	MEDULLA OBLONGATA
Basal or effector lamina, <i>i.e.</i> , the ventral grey column.	1. Medial somatic column. Nucleus of abducent nerve. Nucleus of hypoglossal nerve.
	2. Lateral somatic column. Effector nucleus of trigeminal nerve. Effector nucleus of facial nerve. Effector nucleus (nucleus ambiguus) of vago-glosso-pharyngeal nerve. Effector nucleus of accessory nerve.
Lateral or visceral grey column.	3. Splanchnic column. Effector nuclei of fibres to unstriated muscle passing through the facial and vago-glosso-pharyngeal nerves.

SPINAL CORD

Alar or receptor lamina, *i.e.*, the dorsal grey column.

MEDULLA OBLONGATA

1. Receptor nuclei of receptor nerves from thoracic and abdominal viscera.
2. Receptor nuclei of the intermediate and glossopharyngeal nerves of taste.
3. Receptor nuclei of the cochlear nerve of hearing.
4. Receptor nuclei of the vestibular nerve of equilibration.
5. Gracile and cuneate nuclei.

Not present in the spinal cord.

1. The three olivary nuclei.
2. The arcuate nuclei.

Decussations of Tracts within the Medulla Oblongata. Within the medulla oblongata, the great effector and receptor pathways undergo decussation, and do so at different levels. The consequences of these decussations so profoundly modify the internal construction of the medulla as to make it essential that they should be understood.

The Decussation of the Pyramids. Seventy-five per cent of the "descending" motor or effector fibres decussate, at the junction of the medulla and spinal cord, to take up their positions in the lateral white funiculus of the latter, as the lateral cortico-spinal or crossed pyramidal tracts. These fibres, in their passage from one side to the other, form the *decussation of the pyramids*. The decussating fibres pass right through the ventral grey column of the cord, and therefore the first and most obvious effect of the decussation, as seen in the medulla, is the division of the ventral grey column into two parts. Of these the *basal part* remains on the ventrolateral aspect of the central canal. The *detached part* is set free, and from its large, multipolar cells arise, in part, the ventral effector roots of the first cervical spinal nerve and the accessory nerve. This detached part, which represents the head of the column, eventually disappears at the level of the lower extremity of the inferior olivary nucleus. Another effect of the decussation of the pyramids is the displacement,

dorso-laterally, of the ventral fasciculus proprius, which here becomes continuous with the medial longitudinal tract.

The Pyramids of the Medulla. The pyramids of the medulla are the large somewhat rounded bundles of longitudinal effector fibres which lie on either side of the ventral median fissure of the medulla, and contain all the fibres of the lateral and anterior cortico-spinal tracts of the spinal cord. The fibres of the former cross over to the opposite side at the decussation of the pyramids, whilst those of the latter remain on the same side as the anterior cortico-spinal tract. There is great individual variation in the fibres of these tracts, which may even amount to asymmetry.

The Decussation of the Fillet. The decussation of the fillet or lemniscus, is a discussion of receptor axons derived, in part, from the cells of the gracile and cuneate nuclei. It takes place in the medulla at a higher level than the decussation of the pyramids, and the axons which compose it are known as *internal arcuate fibres*. These fibres arise, as just stated, in the gracile and cuneate nuclei, and cross over to the opposite side, and, at the point of crossing, form the decussation of the fillet (lemniscus) or the "sensory" fillet. After the decussation, the axons turn upwards and finally terminate in the thalamus. In their upward course the axons of the fillet form a broad ribbon-like band—hence the name—which lies close to the median raphe, medial to the inferior olivary nucleus, and dorsal to the pyramid. By the subsequent addition of other internal arcuate fibres the fillet, subsequent to the decussation, increases in size and spreads out dorsally until, at the level of the middle of the olive, it is only separated from the grey matter of the floor of the fourth ventricle by the medial longitudinal tract.

The actual decussation of the fillet itself commences at the upper border of the decussation of the pyramids and extends upwards as far as the middle of the olive. Its fibres cut through what remains of the grey matter after the decussation of the pyramids, and still further submerges the medial longitudinal tract, which now comes to lie close to the grey

matter of the floor of the fourth ventricle and in immediate contact with the median raphe. Once the decussations of the pyramids and fillet have been completed, there are, in the medulla, three important longitudinal tracts all close to the median raphe, which are, in ventro-dorsal order, the pyramid, the fillet, and the medial longitudinal tract. The relative

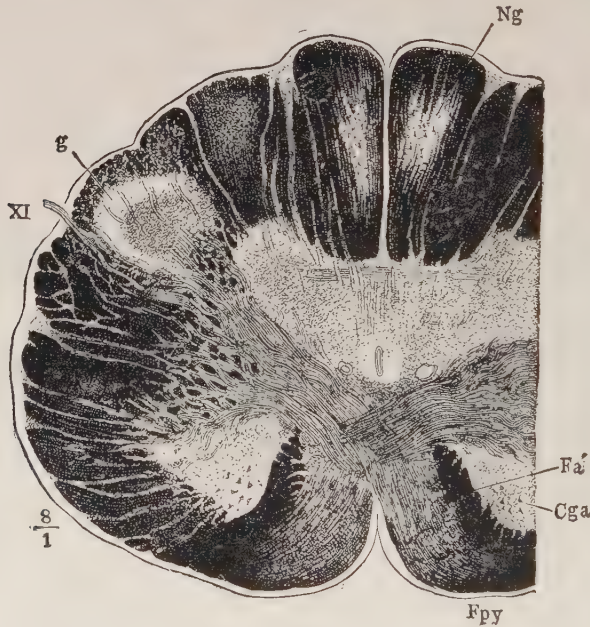


FIG. 39.—Transverse section of medulla oblongata near the decussation of the pyramids. (Henle.) *Fpy*, pyramidal tract; *Cga*, ventral horn; *Fa'*, rest of ventral horn; *Ng*, nucleus of funiculus gracilis; *g*, substantia gelatinosa; *XI*, spinal accessory. (From: Luciani, "Human Physiology.")

positions of these important longitudinal tracts is not again materially altered.

The *medial fillet* is thus part of a direct physiological path of nerve fibres which arises in the nerve cells of the gracile and cuneate nuclei, and terminates in the thalamus after traversing the brain stem. It constitutes the second series of neurons over which receptor impulses are conveyed to the

thalamus. To different portions of these secondary series of neurons different names are applied, such as arcuate fibres, decussation of the fillet, inter-olivary fillet, and medial or "sensory" fillet.

The Arcuate Fibres. The arcuate fibres are chiefly the axons of cells situated in the gracile and cuneate nuclei, and some of them take part in the formation of the decussation of the fillet. Those of the arcuate fibres which traverse the reticular formation of the medulla constitute the internal

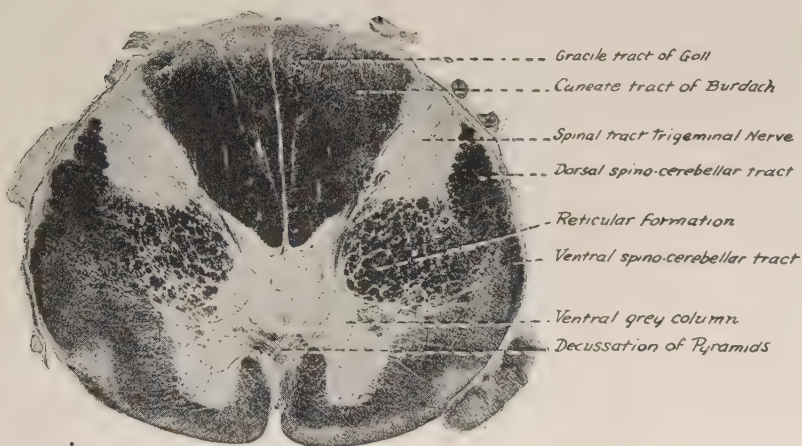


FIG. 40.—Microphotograph of a section through the medulla oblongata at the level of the decussation of the pyramids.

arcuate fibres, and those which run over the surface of the medulla, form the external arcuate fibres.

The *internal arcuate fibres* comprise (1) those fibres which, arising in the gracile and cuneate nuclei, cross over to the opposite side in the decussation of the fillet, and subsequently ascend to the thalamus; (2) receptor fibres of the second order, arising in the cells of the recipient nuclei of the sensory or receptor cerebral nerves, and ascending in the fillet to the thalamus; and (3) olivo-cerebellar fibres to be subsequently described.

The *external arcuate fibres* are not so well known as the internal. They appear to comprise (1) the posterior or dorsal external arcuate fibres, which arise in the gracile and cuneate nuclei and, entering the restiform body of the same side, pass to the cerebellum. (2) The anterior or ventral external arcuate fibres arise in the gracile and cuneate nuclei of one side, decussate in the fillet, gain the surface of the medulla by passing between, or through, the pyramids, or between them and the olives, and then sweep around the external surface of the medulla to enter the restiform body

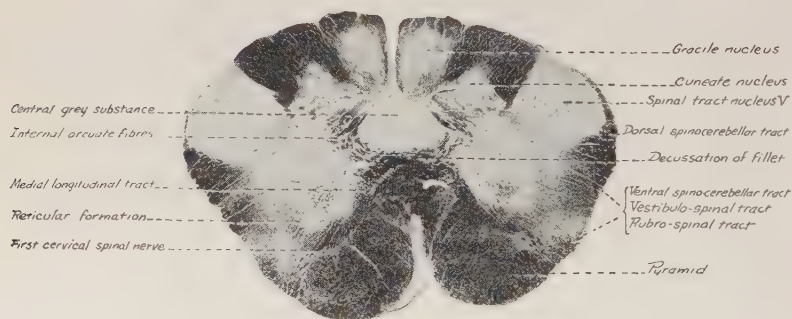


FIG. 41.—Microphotograph of a section through the medulla oblongata at the level of the decussation of the fillet.

and the cerebellum on the side opposite to that whence they arose.

Whilst these facts relative to the external arcuate fibres are quite well established, they do not account for the whole of the external arcuate fibres, the origin and course of the majority of which are still obscure.

The Restiform Body or Inferior Cerebellar Peduncle. The restiform body is a large and massive strand of white fibres which gradually accumulates along the lateral border of the lower part of the fourth ventricle. It connects the spinal cord and medulla oblongata to the cerebellum, and comprises, therefore, a spinal and medullary series of tracts.

The *spinal part* of the restiform body comprises (1) the direct or dorsal spino-cerebellar tract of Flechsig, the fibres of which arise in the dorsal nucleus of Clarke in the spinal cord, and end in the cortex of the superior vermis of the cerebellum of the same side, though possibly some may pass over to the vermis of the opposite side. By this route are transmitted proprio-ceptive impulses from muscles, joints, and tendons; (2) the ventral and dorsal external arcuate fibres form a secondary connection from the cuneate and gracile tracts of Burdach and Goll, and so establish direct and crossed

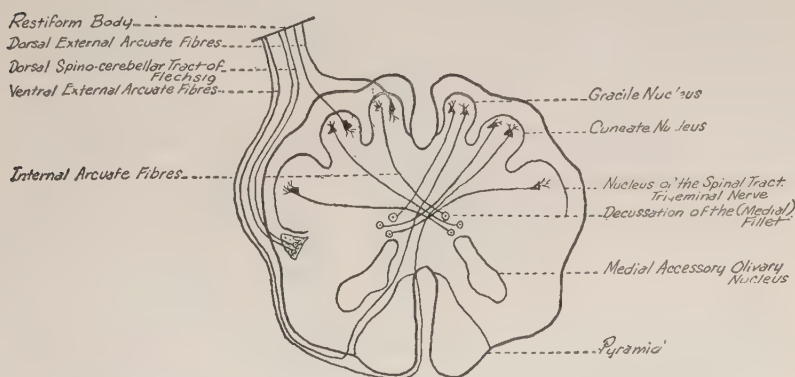


FIG. 42.—Diagram to illustrate the arcuate fibres of the medulla.
See pages 181, 182.

connections for proprio-ceptive impulses from muscles, joints, and tendons, and possibly also for some extero-ceptive impulses from the skin. It is apparently by this route that most of the impulses traversing the gracile and cuneate tracts of the spinal cord are conveyed to the cerebellum instead of to the cerebrum.

The *medullary part* of the restiform body is chiefly composed of (3) olivo-cerebellar fibres, direct and crossed, which connect both the inferior olivary nuclei of the medulla with the cerebellum, so assisting in the co-ordination of the movements of the head with those of the eyes; (4) the Deitero-cerebellar tract connects the nucleus of Deiters, one of the recipient nuclei of the vestibular nerve of equilibration, with

the roof nuclei of the cerebellum, so serving for the most important of the proprioceptive functions, namely, equilibrium control; (5) the nucleo-cerebellar tract passing from the recipient nuclei of the trigeminal, facial, vestibular, and vagoglossopharyngeal nerves to the cerebellum.

The Deitero-cerebellar and nucleo-cerebellar tracts tend to be more detached from the restiform body than those previously mentioned, hence they are not always included as forming part of the restiform body, but as forming a juxta-restiform body.

All the constituent tracts of the restiform body, as just enumerated, are receptor cerebellar tracts, that is, they convey impulses to the cerebellum. There is, however, believed to be at least one effector tract passing through the restiform body, and that comprises axons passing from the roof nuclei to the vestibular nuclei, and thence by the vestibulo-spinal tract to the medulla and spinal cord.

The Indirect or Ventral Spino-cerebellar Tract of Gowers.

The ventral spino-cerebellar tract of Gowers continues to pass upwards through the medulla on the periphery in much the same position as it occupies in the spinal cord. It ascends thence through the reticular formation of the pons, and eventually enters the cerebellum.

The Spinal Tract of the Trigeminal Nerve. The spinal tract of the trigeminal nerve is formed by the descending receptor axons of that nerve, and is responsible for the elevation on the surface of the medulla, known as the tuberculum cinereum. The tract is more fully described elsewhere.

Summary of the Fate of the Chief Tracts of the Spinal Cord within the Medulla. The main white tracts having now been considered, the following summary of their fates within the medulla, may be usefully considered.

Proprioceptive tracts of the spinal cord. Of the proprioceptive tracts of the spinal cord, the *cuneate* and *gracile tracts* terminate in the cuneate and gracile nuclei of the medulla. There the impulses are transferred to a second series of neurons which pass either (a) to the cerebellum through the

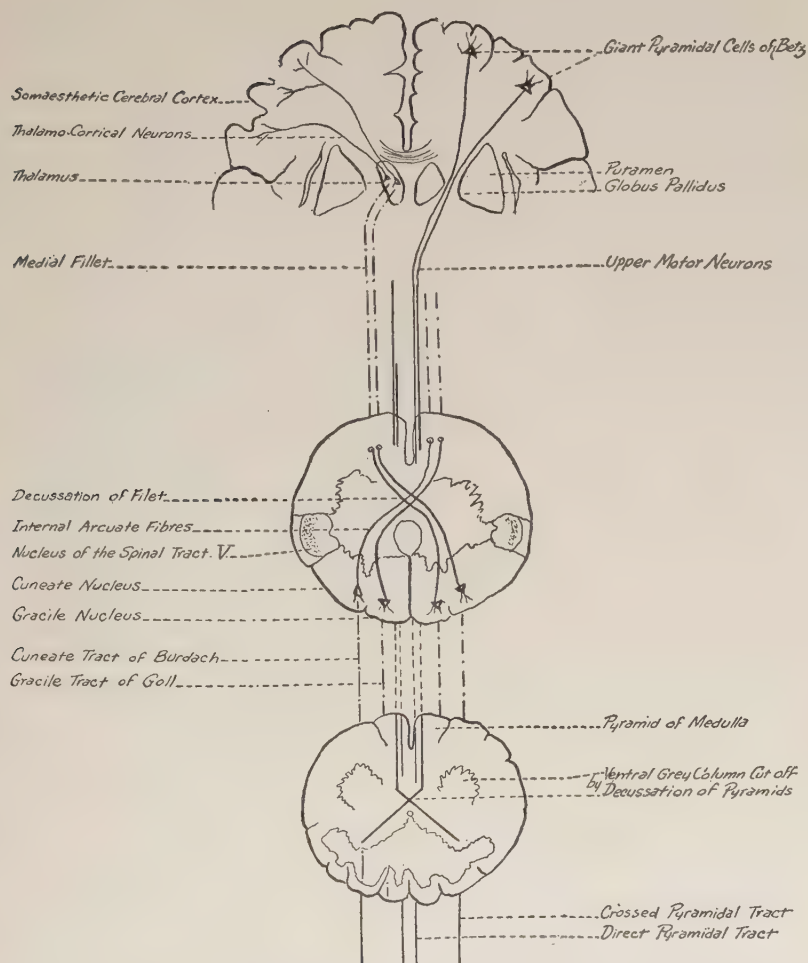


FIG. 43.—Diagram to show the decussations of the pyramids and fillet in the medulla. See pages 107, 135, 145, 178, 179, 181, 382, 386.

arcuate fibres, or (b) to the thalamus through the fibres of the fillet. The *dorsal spino-cerebellar tract of Flechsig* passes through the restiform body to the cerebellum. The *ventral spino-cerebellar tract of Gowers* passes right through the medulla to the pons, and turns thence into the cerebellum.

Extero-ceptive tracts of the spinal cord. Of the extero-ceptive tracts of the spinal cord, the spino-thalamic tracts come together in the medulla as the spinal fillet, which, joining the fillet, passes upwards through the medulla, to the thalamus.

Intersegmental tracts of the spinal cord. Of the several intersegmental tracts of the spinal cord the anterior fasciculus proprius establishes continuity with the medial longitudinal tract, but the position of the latter becomes displaced by the two great medullary decussations (pyramids and fillets) from the ventral to the dorsal side.

Effector tracts of the spinal cord. Of the several effector tracts of the spinal cord those which have a definite and recognisable position in the medulla are the anterior and lateral cortico-spinal tracts which occupy the pyramid, the latter also constituting the decussation of the pyramids.

As the medulla also establishes its own connections with structures which have no representation in the spinal cord, it follows that other tracts are found in the medulla, such as the olivo-cerebellar tracts, the spinal tract of the trigeminal nerve, and the numerous smaller tracts which are scattered through the reticular formation of the medulla.

Grey Matter of the Medulla Oblongata. The grey matter of the medulla differs altogether from that of the spinal cord, and does so in two important respects; first, it is not confined to the interior as in the spinal cord, and second, it is not sharply differentiated from the white matter, but is intermingled therewith. The explanation of the change in position from the interior to the exterior has been given on page 172, whilst the cause of the intermingling has just been seen to be due to the great decussations of the pyramids and fillet which occur in the medulla.

It consequently follows that the grey matter of the medulla bears no resemblance to that of the spinal cord, but is found in the form of discrete nuclei and a reticular formation, that is, a commingling of grey and white matter, and should be considered under these two heads.

Discrete Nuclei of the Medulla. Within the medulla the grey matter is, at certain places, collected together into well marked and easily recognisable nuclei, which include the gracile and cuneate nuclei, the olivary nuclei, the arcuate nuclei, and the nuclei of the associated cerebral nerves.

Gracile and Cuneate Nuclei. The gracile and cuneate nuclei

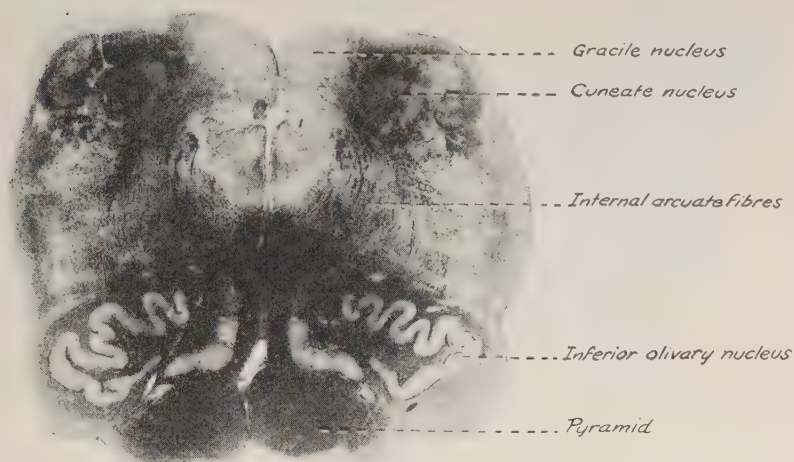


FIG. 44.—Microphotograph of a section through the medulla oblongata at the level of lower part of the olive.

are two large masses of grey matter found in the posterior or dorsal funiculi of the lower part of the medulla. The axons of the gracile and cuneate tracts of the spinal cord terminate within these nuclei, and establish there synaptic continuity with the secondary series of neurons which have their cell stations within these nuclei. The axons of these secondary neurons form the arcuate fibres as has already been described.

The presence of the gracile and cuneate nuclei within the

medulla give rise to the clava and cuneate tubercle on the surface, and as the fourth ventricle opens out the nuclei of opposite sides gradually become separated and finally disappear with the complete formation of the restiform body.

The Olivary Nuclei. The olivary nuclei are three in number on each side of the medulla, namely, the inferior, medial accessory, and dorsal accessory.

The *inferior olivary nucleus* lies subjacent to the olive, and is a structure peculiar to the medulla. It presents in trans-

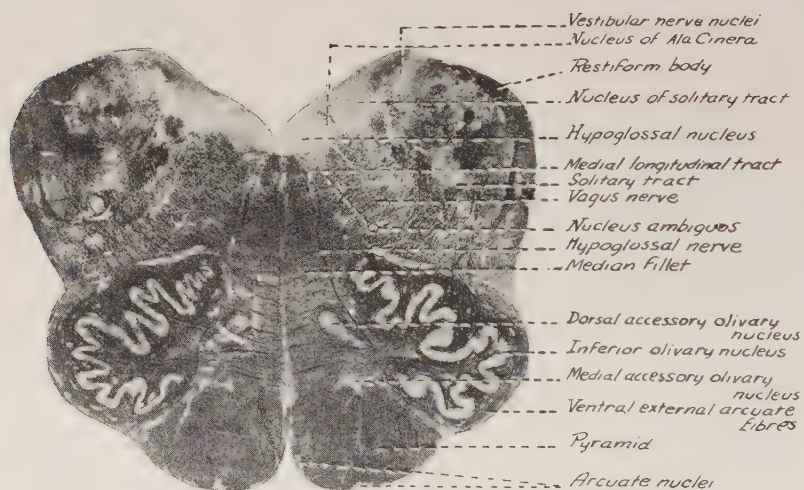


FIG. 45.—Microphotograph of a section through the medulla oblongata at the level of the middle of the olive.

verse section the appearance of a thick, wavy, or undulating line of grey matter, folded on itself so as to enclose a space filled up with white matter. The open part is directed towards the median line, and is termed the hilus. Into, and out of, the hilus stream numerous axons, which constitute the olivary peduncle, and form the *olivo-cerebellar tract*. The inferior olivary nucleus is strongly developed only in man and the higher apes, and its size appears to be correlated with that of the lateral hemisphere of the cerebellum, and not with that of the cerebrum.

The two accessory olivary nuclei appear, in transverse section, as rods. The *medial accessory olivary nucleus* lies between the hilus of the inferior olivary nucleus and the fillet, whilst the *dorsal accessory olivary nucleus* lies on the immediate dorsal side of the inferior olivary nucleus itself.

The inferior olivary nucleus consists of many rounded cell bodies embedded in neuroglia, the axons of which pass out of the hilus as olivo-cerebellar fibres. These fibres cross the median line, and are then joined by uncrossed olivo-cerebellar

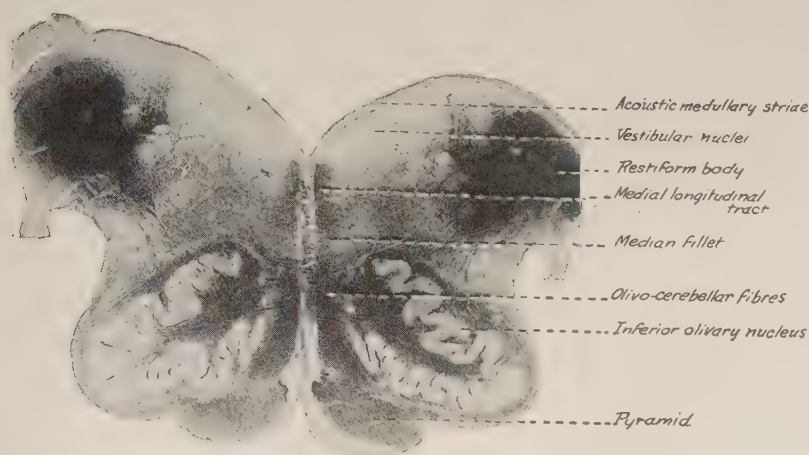


FIG. 46.—Microphotograph of a section through the medulla oblongata at the level of the upper part of the olive.

fibres from the inferior olivary nucleus of that side, after which they pass, as internal arcuate fibres, through the restiform body to the cerebellum, thus forming what is sometimes known as the *olivo-cerebellar tract*. The exact significance of this connection is not clear. It is believed that, within the nucleus itself, certain receptor axons, the origin of which is not known, form synaptic connection with the neurons of the olivo-cerebellar tract, and that connections are also here established with neurons descending from the thalamus, as well as with other ill-defined ascending receptor axons from the spinal cord, known as the *spino-olivary tract*.

The Arcuate Nuclei. The arcuate nuclei are small irregular patches of grey matter found on the ventral side of the pyramid, above the level of the decussation of the pyramids. They appear to be homologous with the nuclei pontis, and are not improbably relay stations in the path of cortical axons descending by way of the pyramidal tracts, and thence on to the cerebellum by means of the ventral external arcuate fibres.

The Nuclei of the Cerebral Nerves. The nuclei of those cerebral nerves which have their situations in the medulla are those of the hypoglossal nerve, the nucleus ambiguus, which gives origin to certain effector fibres of the glosso-pharyngeal, vagus, and accessory nerves, the dorsal effector nucleus of the vagus nerve, and the nucleus of the solitary tract, which is the receptor nucleus for certain of the receptor fibres of the facial, glosso-pharyngeal, and vagus nerves. All these are considered with the cerebral nerves themselves.

The Reticular Formation. It has already been seen that the grey matter of the medulla differs altogether from that of the spinal cord. Instead of being massed in a solid H-shaped column it is, in the medulla, broken up into isolated discrete nuclei, or is intermingled with the white matter. To this latter portion of medullary grey matter is applied the term, *formatio reticularis*.

The reticular formation of the medulla fills up all the interstices between the larger white tracts of the medulla and the discrete grey nuclei. It is thus composed of small islands of grey matter interspersed between the medullated axons passing in various directions, chiefly longitudinal or transverse, and is divided into a white and a grey reticular formation.

The *white reticular formation*, as its name implies, is chiefly composed of white tracts with only a small amount of grey matter in the interstices, and lies mostly on the medial side of the emerging axons of the hypoglossal nerve, and dorsal to the pyramid. Passing through it are the medial fillet, the tecto-spinal tract, and the medial longitudinal tract.

The *grey reticular formation* lies lateral to the emerging axons of the hypoglossal nerve and dorsal to the olive. Nerve

cells predominate within this area, hence its name of grey reticular formation. Within this area are found the transversely directed internal arcuate fibres, and certain important longitudinally directed axons. Amongst these are the descending rubro-spinal tract, the thalamo-olivary tract, the ascending ventral and dorsal spino-cerebellar tracts, and the spino-thalamic and spino-tectal tracts.

As regards the *nerve cells* of the grey reticular formation, they are scattered through the formation, but in certain localities have a tendency to form nuclei, the connections and functions of which are not as yet clearly understood, though Cajal and van Gehuchten have described certain connections between some of these cells and spino-cerebellar tracts. It is not improbable that many of the cells of the grey reticular formation are intimately associated with many of the reflex activities of the medulla.

Three Areas of Flechsig. Flechsig has pointed out that if transverse sections be made through the open part of the medulla, the lines of exit of the vagus and hypoglossal nerves naturally divide the medulla into three areas, and as this subdivision is of some assistance in the recognition of structures in the medulla, the method is of practical utility to the student.

The *ventral area* is bounded medially by the raphe, and laterally by the hypoglossal nerve, and contains, in approximately ventro-dorsal order, the arcuate nuclei, the pyramid, the interolivary stratum of the fillet, the medial accessory olivary nucleus, the white reticular formation, and the medial longitudinal tract.

The *lateral area* lies between the emerging hypoglossal and vagus nerves, and contains in approximately ventro-dorsal order, the inferior olivary nucleus, the dorsal accessory olivary nucleus, the nucleus ambiguus, the grey reticular formation, and the nucleus of the ala cinerea.

The *dorsal area* lies on the dorsolateral side of the emerging vagus nerve fibres. Within its limits may be found the restiform body, the spinal tract of the trigeminal nerve, the cuneate

nucleus in part, the nuclei of the vestibular nerve, and the solitary tract.

Functions of the Medulla Oblongata. From what has been said as to its evolutionary history it is clear that the medulla is a specially important region of the nervous system, and its integrity is vital to the maintenance of life. It not only serves as a connecting link for almost all nerve impulses from lower to higher levels, but it is also the special seat of those reflex nerve centres which control the activity of the circulatory, respiratory, and alimentary organs. Some of those portions of the medulla which exercise these functions are termed the *respiratory* and the *vasomotor* (*vasoconstrictor*) centres. These centres are of the utmost importance, on account of their extensive connections with all parts of the body, their activity, which is independent of the higher centres of the brain, and the absolutely vital character of the regulations they effect. *Conscious* sensation, motion, ideation, memory, and so on, have been transferred to the brain, but the *unconscious* and *involuntary* regulations of the organs of circulation and respiration, and, to a certain extent, of other viscera, have been retained and centralised in the medulla.

The exact position and nerve connections of the respiratory and vaso-motor centres are not yet definitely determined, but it is not improbable that the *respiratory centre* is bilaterally situated in the dorsal part of the medulla, at about the level of the calamus scriptorius, that the axons pass down the ventro-lateral column of the cord, and arborise around the effector cells in the ventral grey column of those axons which pass to the respiratory muscles. These medullary centres are probably intimately associated with the autonomic nervous system and its central connections.

As examples of others of the simpler reflex actions in which the medulla oblongata is concerned, may be mentioned the *coughing reflex*, where receptor impulses are conveyed centrally by branches of the vagus nerve to the respiratory centre of the medulla, and thence by the effector paths to the muscles; the *swallowing reflex*, where receptor impulses are trans-

mitted from the pharyngeal mucous wall, through the vago-glosso-pharyngeal nerves, to the effector nuclei of those nerves, and so on, as effector axons, through the same nerves; the *vomiting reflex*, where receptor axons of the vago-glosso-pharyngeal or other nerves may be abnormally stimulated, the *salivary reflex*, the *sneezing reflex* and the *suckling reflex* of the infant are also examples of medullary reflex activities.

Summary of the Medulla Oblongata. The *grey matter* of the medulla oblongata is its essential active substance, and is especially concerned with many of the vital processes of life, by means of those reflex activities, some of which have just been mentioned. The grey matter of the medulla thus exercises an essential control over respiration, cardio-vascular activity, phonation, articulation, deglutition, digestion, secretion and metabolism.

Through the *white matter* of the medulla oblongata pass all the major conduction neuronie paths which serve to maintain efficient relations between the receptors and effectors of the body, and it also contains many of their most important decussations. The latter may be summarised thus:

The *decussation of the pyramids*, that is, of the cortico-spinal effector pathway for volitional control of muscles.

The *decussation of the fillet (lemniscus)*, that is, of the spino-thalamic pathway for discriminative sensibility.

The *olivo-cerebellar decussation*, that is, of fibres passing from the inferior olivary nuclei of the medulla to the cerebellum, the functions of which are not very clear.

The *arcuate decussation*, the *trigeminal decussation*, and the *vestibular nerve decussation*, of which the names are sufficiently explanatory.

CHAPTER XV

THE EVOLUTIONARY HISTORY OF THE PONS

The Pons a Mammalian Characteristic. The pons is found only in mammals, and attains its highest development in the anthropoid ape and man. It is *not* found in fishes, amphibia, reptiles or birds.

In the *lower vertebrates*, the tegmentum of the myelencephalon (medulla oblongata) is continuous with that of the metencephalon (dorsal part of the human pons) without appreciable line of demarcation. This common tegmental area forms a central autonomous region essential to the regulation of the vital processes of life, through which are mediated the necessary reflex activities. In *mammals*, consequent on the advent of a neo-pallial cerebral hemisphere, there is added to the pontine region, a basilar pons which is swung, like a suspension bridge, across the ventral surface of the tegmentum of the metencephalon (dorsal pons) from the cerebellum by means of the middle cerebellar peduncles or the brachia pontis. It thus comes to form one of the *three major divisions of the metencephalon*. These three divisions are, in the order of their evolutionary appearance:

1. The *tegmentum* or *dorsal pons*, which is the primitive segmented portion of the metencephalon, and is common to all vertebrates.

2. The *cerebellum*, an early supra-segmental derivative of the neural tube, which is variable in its development through the vertebrate series. The variability being dependent upon the locomotory and equilibratory requirements of the animal.

3. The *pons Varolii* or *basilar pons*, a more recently acquired structure and present in mammals only.

Functional Significance of the New Pons. From the above facts it is evident that the new or basilar pons must have a

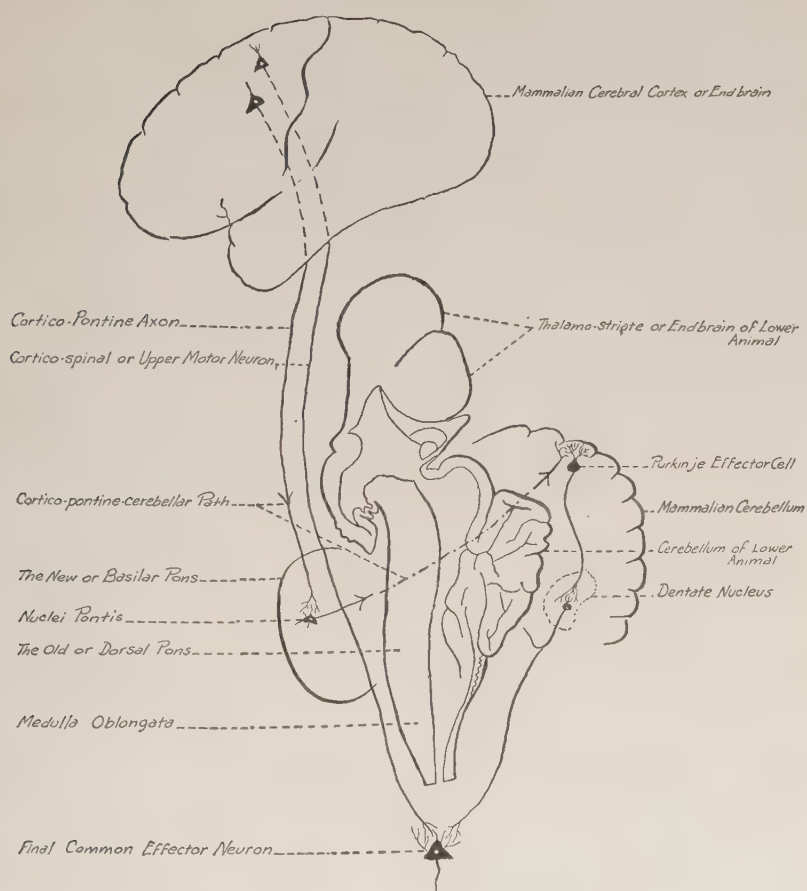


FIG. 47.—Diagram to show how the addition of a pallial cortex to the neuraxis necessitates the further addition of a new or basilar pons.

significance peculiar to the development of mammals. Even among the mammals themselves the basilar pons varies in size and structure. In the lower mammalian forms it is small and does not entirely cover the ventral surface of the metencephalon. In the anthropoid apes and man it is the most prominent element on the ventral surface of its region.

The explanation of the special significance of the basilar pons in mammals is that its principal constituents are nerve fibres which participate in establishing a connection between the cerebral cortex and the cerebellum. In the lower animal forms any such connection is not possible, on account of the absence of a neo-pallium. In man this cerebro-ponto-cerebellar connection far exceeds in size that between the "motor" cerebral cortex and the spinal cord, that is, the pyramidal effector system.

The *cerebro-ponto-cerebellar neurons* have their cell stations in the frontal, parietal, temporal, and occipital regions of the cerebral cortex, and they establish communications with the lateral lobe of the cerebellum of the opposite side. The cerebellum is thus brought under the influence of those regions of the cerebral cortex which are related to volitional control of muscles, and to somatic, auditory and visual sensibility. A clue to the physiological nature of this cerebro-ponto-cerebellar connection is given in the functions commonly attributed to the cerebellum. This part of the neuraxis is now regarded as the important organ of synergic control. The regulation of motion mediated through the cerebellum thus comes under the influence of the auditory, visual, and somatic sensory and motor activities of the cerebral cortex. Man has the greatest need of such influences; the lower mammals require much less. Among mammals, although synergic regulation is necessary, there are salient differences in the control of motion.

Motor Activities of Mammals. The motor activities of the *lower animal* are, to a great extent, limited to performances which are common to its kind. A quadruped has a range of action peculiar to its species, and the animal is able to go but little beyond this limit, however much it may be trained.

In large measure its motor activities are *phylogenetically* conditioned, that is, they are part of the heritage of its species. Although much of the motor activity in *man* is similarly conditioned, there has been created an extensive superstructure of volitional control, in consequence of which the individual is capable of expanding his motor accomplishments to a remarkable degree. By far the greater part of human motor activity is *ontogenetically* conditioned, that is, it is dependent upon what the individual makes of it. Such is the case with speech and handwriting and many artistic and skilled accomplishments which are individual acquirements.

Skilled acts of the kind just mentioned have greater need of synergic control than more simple motor performances, and on this account the synergic organ of the neuraxis has acquired close communication with the visual, auditory, and somatic sensory and motor areas of the cerebral cortex, in the special interests of adequate supervision of these motions. *Skilled movements vary in direct ratio with intelligence*, hence the clumsiness of many aments. The higher the intelligence, the richer the cerebro-ponto-cerebellar connections which determine the synergic control. The *modus operandi* of this cerebro-ponto-cerebellar connection is best conceived by picturing the course of a motion formula for a skilled act such as handwriting. This arises in the neo-pallial cerebral cortex and leaves it by way of the cortico-spinal or pyramidal effector pathway, in order to reach the volitional muscles. *Simultaneous* with the despatch of these cerebral impulses to the muscles, others leave the frontal, visual, sensory, and auditory areas of the cerebrum for the cerebellum, and have, as their purpose, the arousing of the necessary synergic control which is to regulate the muscles participating in the skilled acts to be accomplished.

Summary. The *basilar* or *new pons* is, therefore, significant as an index of the degree of skilled movement of which the animal is capable. The *dorsal* or *old pons* is complementary to the medulla oblongata in the regulation of the vital processes, and participates in the important control of the eyes. (Tilney and Riley.)

CHAPTER XVI

THE MINUTE STRUCTURE OF THE PONS

The Two Parts of the Pons. The human pons consists of two parts which differ considerably both in size and in functional significance, and in cross sections these two parts can be easily distinguished, even by the naked eye.

The *dorsal or tegmental part of the pons* resembles the medulla, of which it is the cerebral continuation. It forms the primitive pons and is present in all vertebrates. Functionally, it is an extension of the medulla.

The *ventral or basilar part of the pons*, larger than the dorsal or tegmental pons, is a recent evolutionary addition, and is only found in mammals, that is, in those animals with a true cerebral pallium, in which it forms part of the conducting path between the pallium on the one hand, and the cerebellum and spinal cord on the other. It is, therefore, in this part of the pons that there are found those longitudinal

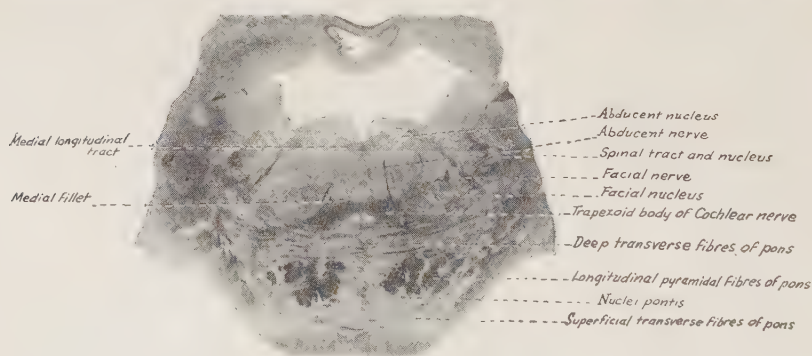


FIG. 48.—Microphotograph of a section through the lower part of the pons at the level of the roots of the facial and abducent nerves.

axons which go to form the pyramids of the medulla, and it is composed of these structures, together with other structures peculiar to this level.

The Pons As a Whole. The pons belongs to the brain stem, and is, therefore, part of the connecting link between the spinal cord and the cerebrum. Through it pass all the great longitudinally directed receptor and effector pathways which have been traced from spinal cord to medulla, or *vice versa*. In the main, these preserve the same general positions in the pons as in the medulla oblongata. The pons, however, establishes some new connections of its own, the chief of which are the central pathways of the cochlear nerve of hearing, the vestibular nerve of equilibration, and the connections of the cerebrum with the cerebellum, the last of which necessitate the addition to the primitive dorsal or tegmental pons of a ventral or basilar pons, through which the connections concerned are made.

These additions and alterations, with their associated collections of discrete nuclei, naturally modify the transverse sectional appearances of the human pons as compared with either the medulla or spinal cord. Consequent on the introduction of the, at first, transversely directed fibres of the cochlear nerve of hearing into the pons, transverse sections, even as seen with the naked eye, show quite clearly the subdivision of the pons into its two parts, the old or dorsal pons, and the new or basilar pons.

The Ventral, Basilar, or New Pons. The basilar or new pons is the larger of the two divisions. It is made up of longitudinal axons, intersected by transverse axons, with grey matter, known as the nuclei pontis filling up the interstices between the intersecting axons.

The Longitudinal Axons of the Basilar Pons. The longitudinal axons found in the basilar pons are of two kinds:

1. Those of the cortico-spinal tract, continued through the pons into the pyramids of the medulla.
2. Those of the cerebro-ponto-cerebellar tracts, some of which are relayed in the grey matter of the nuclei pontis.

The *longitudinal pyramidal* or *cortico-spinal axons* consist of the fibres which eventually form the pyramids of the medulla and the cortico-spinal tracts of the spinal cord. At the upper and lower ends of the pons the longitudinal fasciculi of the pons form two compact bundles, but in the intermediate parts of the pons they become much broken up by the superficial and deep transverse fibres of the pons, and are thus spread out over a wider area.

The number of longitudinal pontine pyramidal fibres which enter the pons from the cerebrum is much larger than those which leave it. This is because those which enter the pons comprise both series, *cortico-spinal* and *cerebro-ponto-cerebellar*, and many of the latter terminate, as stated, in the nuclei pontis, where a fresh series of axons, the transverse fibres of the pons arise, and continue the path on to the cerebellum.

The Transverse Fibres of the Pons. The transverse fibres of the pons, or the *fibræ pontis*, are a number of more or less transversely directed nerve fibres, which pass from the pons

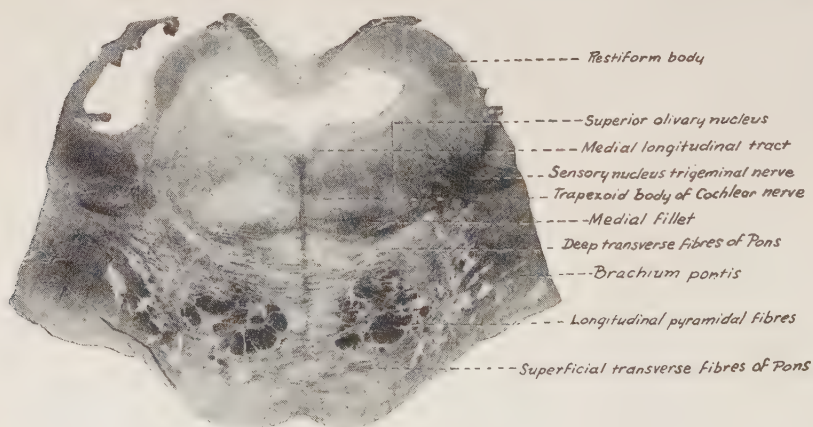


FIG. 49.—Microphotograph of a section through the pons at the level of the roots of the trigeminal nerve.

to the cerebellum, and form part of the cerebro-ponto-cerebellar pathway already referred to. They are collected laterally into one compact mass which enters the white medul-

lary body of the cerebellum, and is termed the *middle cerebellar peduncle* or the *brachium pontis*.

The transverse fibres of the pons arrange themselves, in reference to the longitudinal pyramidal fibres, somewhat differently at different levels of the pons; thus, at its lower or medullary border most pass on the ventral side of the longitudinal fasciculi; at higher or more cranial levels the numbers of the transverse fibres of the pons increase, and pass through, and dorsal to, the longitudinal pyramidal fibres. This difference in the relations of the transverse fibres of the pons to longitudinal pyramidal fibres permits of the subdivision of the former into superficial and deep. Lastly, in the median plane the transverse fibres of the pons undergo a coarse decussation.

The Nuclei Pontis. The nuclei pontis are the large amounts of grey matter which fill up the interstices between the intersecting transverse and longitudinal fibres of the basilar pons. Their cell bodies are the origins of the axons which form the transverse fibres of the pons, and thus these axons are a part of the physiological pathway from the cerebrum, through the pons, to the cerebellum, that is, of the cerebro-ponto-cerebellar tract.

The nuclei pontis are an upward continuation of the arcuate nuclei of the medulla and contain both stellate cells of varying size and some small Golgi type II cells. Within these nuclei synaptic continuity is established between the cerebro-pontine axons and the ponto-cerebellar, thus completing the physiological neuron chain between cerebrum and cerebellum; similar synaptic continuity is established between certain collaterals from the cortico-spinal tracts and the ponto-cerebellar axons, as also between collaterals from the medial or sensory fillet and the latter. The grey matter of the nuclei pontis represents, therefore, an important association apparatus within which there terminate axons from three different sources.

It is thus clear that the nuclei pontis establish an important, and, for the most part, crossed connection between the

cerebrum and the cerebellum, that is, a cerebro-ponto-cerebellar tract. The *first* series of neurons in the chain, the cerebro-pontine arise from pyramidal cells in the frontal, temporal and other regions of the cerebrum and end in the synapses of the nuclei pontis. From the cells of the latter arise the *secondary* series of axons, the ponto-cerebellar, which cross the median plane, traverse the middle cerebellar peduncle or brachium pontis, and so reach the opposite cerebellar hemisphere.

Some Structural Similarities. Between the basilar or new part of the pons and the pyramidal area of the medulla there is a strong structural similarity, because both these portions represent recent evolutionary additions to the pons and medulla, consequent on the formation of a new endbrain, the neopallial cerebral hemispheres. This similarity may be shown thus:

Superficial transverse fibres.

Medulla.	Ventral external arcuate fibres.
Pons.	Superficial transverse fibres.

Longitudinal fibres.

Medulla.	Pyramid.
Pons.	Longitudinal pyramidal fibres.

Grey nuclei.

Medulla.	Arcuate nuclei.
Pons.	Pontine nuclei.

The Dorsal, Tegmental, or Old Pons. The dorsal or tegmental part of the human pons represents the old pons, and is found in almost all vertebrates. It is an upward continuation of the primitive medulla, and becomes, in its turn, continuous with the tegmental part of the midbrain. It consequently follows that the dorsal or tegmental pons resembles, in its general structure, the medulla. On its dorsal surface the grey matter is spread out, in the form of a thick layer, over the rhomboid fossa. Between this layer of grey matter, and the basilar pons is the reticular formation (admingled grey and white matter) divided by the median raphe into two symmetrical halves, just as in the medulla. It has essen-

tially the same general structure as in the medulla and contains practically the same longitudinal tracts. The restiform body occupies, at first, the same position as in the medulla, but later bends backwards or dorsally into the cerebellum. For these and other structural reasons it follows that trans-

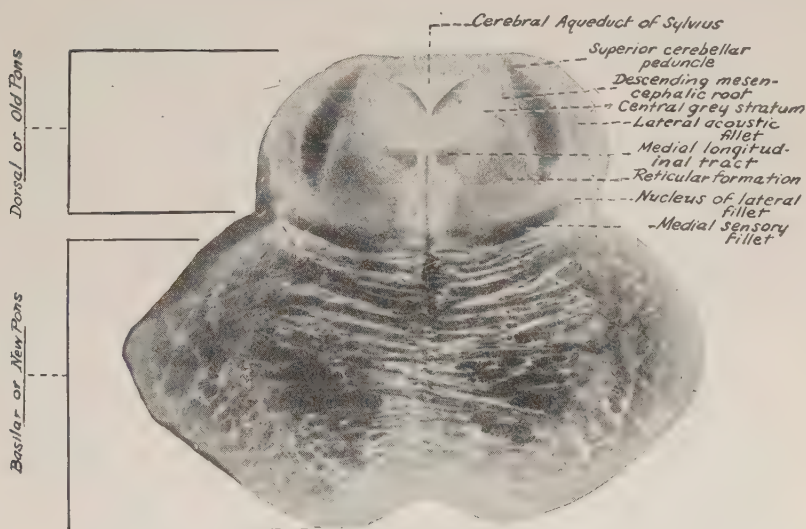


FIG. 50.—Microphotograph of a section through the pons at about its middle.

verse sections made through the upper or mesencephalic part of the pons will differ from those made through the lower or medullary portion.

A transverse section through *the lower part of the dorsal pons*, near its junction with the medulla, shows that the general arrangement of structures, in latero-medial order is somewhat as follows:

The restiform body.

The reticular formation containing—

The spinal tract of the trigeminal nerve and its nucleus.

The nucleus of the facial nerve.

The superior olivary nucleus.

The nucleus of the sixth or abducent nerve.

The medial longitudinal tract.
 The medial fillet.
 The median raphe.

The trapezoid body practically separates the dorsal or tegmental pons from the basilar pons.

A transverse section through *the upper part of the dorsal pons* near its junction with the mid-brain shows quite different appearances, because the restiform body has disappeared into the cerebellum; the acoustic fillet has been formed and is proceeding upwards to the cerebrum, and the cerebello-cerebral connections through the superior cerebellar peduncles

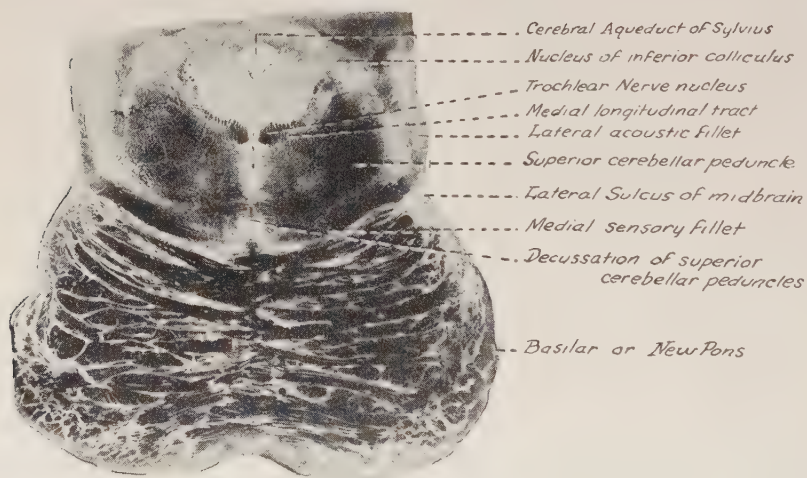


FIG. 51.—Microphotograph of a section through the upper part of the pons and inferior colliculus.

have come into the field. These major structural alterations naturally alter the cross-sectional appearances. There are thus seen in sections through the dorsal pons at this high level, in approximate latero-medial order, the following:

The lateral or acoustic fillet with its nucleus.
 The superior cerebellar peduncle.
 The descending or mesencephalic root of the trigeminal nerve and the locus cæruleus.

The medial longitudinal tract.

The medial or sensory fillet.

The median raphe.

The Central Path of the Cochlear Nerve of Hearing. The cochlear nerve conveys extero-ceptive impulses of hearing centrally, and such impulses traverse at least three series of neurons.

The *first series of neurons* over which such impulses of hearing are conveyed lies within the cochlear nerve itself. These neurons have their cell stations in the spiral ganglion of the cochlea. The *peripheral processes* of these bipolar cells are short, and run from the spiral organ of Corti to the cell body. The *central processes* are longer and run in the cochlear nerve to terminate in two masses of grey matter, placed on the restiform body near the spot in the pons where that body turns backward or dorsally into the cerebellum. These two masses of grey matter constitute the so-called "recipient nuclei of termination" of the cochlear nerve, and are termed, respectively, the *dorsal cochlear nucleus*, and the *ventral cochlear nucleus*. The dorsal cochlear nucleus is placed upon the dorso-lateral aspect of the restiform body and produces there a prominent elevation on the surface of the pons. The ventral cochlear nucleus lies in contact with the ventrolateral aspect of the restiform body, and passes forwards or ventrally towards the interior of the pons.

The *second series of neurons* over which impulses of hearing are conveyed centrally have their cell stations within the dorsal and ventral cochlear nuclei. Those axons which arise from the ventral cochlear nucleus traverse the body of the pons medially and form the *trapezoid body*. The trapezoid body forms a natural line of demarcation between the basilar and dorsal parts of the pons. The axons forming this trapezoid body cross the middle line, and on reaching the lateral border of the opposite superior olivary nucleus, turn upwards in the form of a compact bundle, termed the *lateral* or *acoustic fillet*, to distinguish it from the medial or sensory fillet. Some of the axons forming the trapezoid body

relay in the superior olivary nuclei and in the nuclei of the trapezoid body, whilst others give off collaterals to these nuclei.

The axons arising in the *dorsal cochlear nucleus*, and possibly also some arising in the ventral cochlear nucleus, sweep

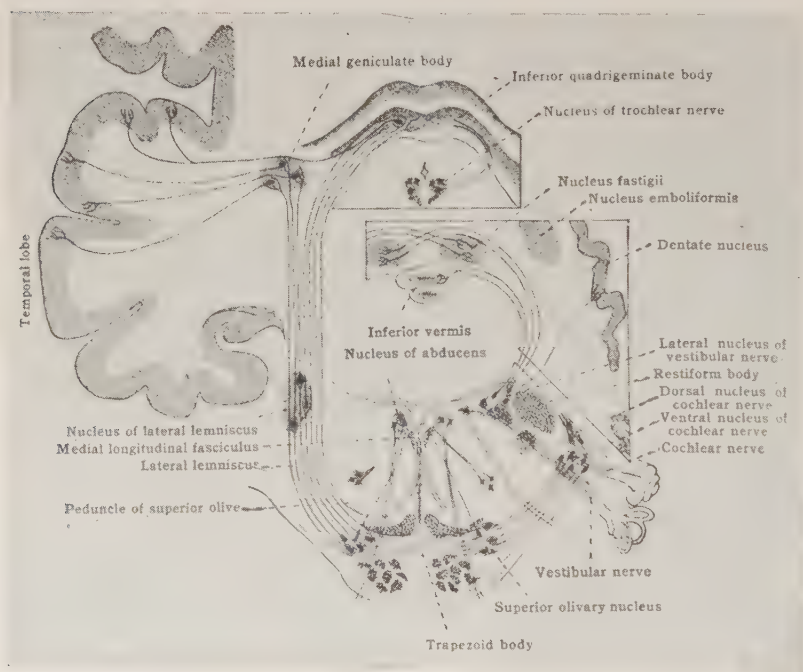


FIG. 52.—Scheme showing some of the central connections of the extero-receptive cochlear nerve of hearing and the proprio-receptive vestibular nerve of equilibration. (From: Morris, "Human Anatomy.")

over the dorsal surface of the restiform body and the floor of the fourth ventricle, where they are sometimes visible to the naked eye, as the *acoustic medullary striae*. On reaching the middle line these axons decussate, sink into the reticular formation of the dorsal pons, and join the trapezoid body of the opposite side. Clinical and experimental evidence suggests that all the axons from the dorsal cochlear nucleus do

not decussate, but some pass centrally in the lateral fillet of the same side.

The *lateral* or *acoustic fillet*, having been formed in the manner indicated by axons from both the dorsal and ventral cochlear nuclei ascends in the reticular formation of the pons to the mid-brain, where its axons terminate, in part, in the inferior colliculus, whilst others proceed to the medial geniculate body through the inferior quadrigeminal brachium. The former acts as a reflex centre in response to sound, whilst the latter is a relay station. Scattered amongst the axons of the lateral or acoustic fillet are many nerve cells, which collectively form the nucleus of the lateral fillet.

Of the several discrete grey nuclei mentioned in connection with the trapezoid body and its upward continuation, the lateral or acoustic fillet, such as the superior olivary nuclei, the nuclei of the trapezoid body, and the nuclei of the lateral fillet, most are relay stations, but according to Cajal, the majority of the axons arising in the superior olivary nucleus belong to short reflex paths in the pontine reticular formation connecting the cochlear nerve with the nuclei of origin of the effector cerebral nerves.

From the *inferior* colliculus and the medial geniculate body a *third series of axons* arise which traverse the medullary substance of the brain to terminate in the auditory centre of the superior temporal convolution, thus completing the central pathway of extero-ceptive auditory impulses.

The Central Path of the Vestibular Nerve of Equilibration. The vestibular nerve conveys proprio-ceptive impulses of balancing centrally, and such impulses constitute the most important of the proprio-ceptive impulses.

The *first series of neurons* over which these proprio-ceptive impulses are conveyed lie within the vestibular nerve itself. These neurons have their cell stations in the *vestibular ganglion*, which lies in the internal auditory meatus. The *peripheral processes* of these bipolar cells are very short, and run from between the sustentacular cells of the maculae of the

semi-circular canals to the cell stations just mentioned. The *central processes* pass into the pons between the restiform body and the spinal tract of the trigeminal nerve towards the acoustic area of the rhomboid fossa, under cover of which they divide into ascending and descending branches. Some of these ascending branches pass without interruption to the vermis

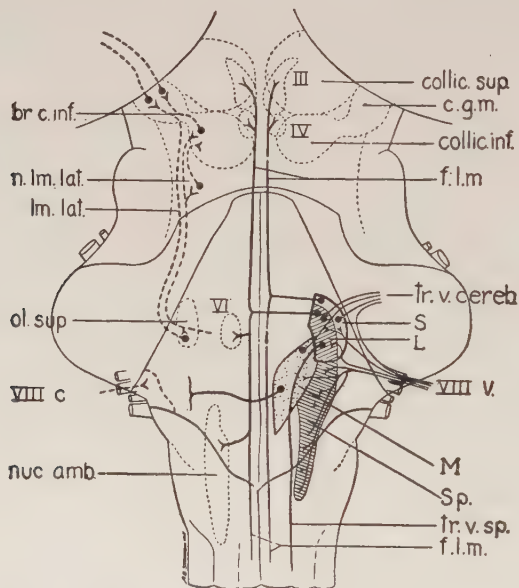


FIG. 53.—Diagram of the nuclei of the vestibular nerve, together with some of the associated fiber tracts. The secondary tracts associated with the vestibular nuclei are drawn in full lines; a part of the secondary auditory path from the cochlear nuclei is drawn in broken lines. *br.c.inf.*, brachium quadrigeminum inferius; *c.g.m.*, corpus geniculatum mediale; *collic. inf.*, colliculus inferior; *collic. sup.*, colliculus superior; *f.l.m.*, fasciculus longitudinalis medialis; *L.*, nucleus nervi vestibuli lateralis (Deiters); *lm. lat.*, lemniscus lateralis; *M.*, nucleus nervi vestibuli medialis (Schwalbe); *n.lm. lat.*, nucleus of lemniscus lateralis; *nuc. amb.*, nucleus ambiguus; *ol. sup.*, superior olive; *S.*, nucleus nervi vestibuli superior (Bechterew); *Sp.*, nucleus spinalis nervi vestibuli; *tr. v. cereb.*, tractus vestibulo-cerebellaris; *tr.v.sp.*, tractus vestibulo-spinalis; *VIII c.*, radix cochlearis of VIII nerve; *VIII v.*, radix vestibularis of VIII nerve. (From: Herrick, "An Introduction to Neurology.")

and cerebellar cortex. The remainder of the ascending, and probably all the descending, branches terminate in one or other of the vestibular nuclei.

The modes of termination of these incoming proprio-ceptive equilibratory axons may, therefore, be summarised thus:

- A. In the cerebellum without synaptic interruption.
- B. In the vestibular nuclei, prior to making other connections.
 1. The principal or medial nucleus.
 2. The descending or spinal nucleus.

3. The superior nucleus of Bechterew.
4. The lateral nucleus of Deiters.

The peripheral processes of the first series of equilibratory neurons just briefly outlined pass from all three semicircular canals, the utricle, and saccule, to the cell stations, and it is not improbable that the central processes of the axons concerned maintain more or less independent paths through the brain stem to their ultimate destinations. If this be correct an explanation would be afforded of certain clinical phenomena presented by disease of these several parts.

From the cells of the recipient vestibular nuclei arise a *second series of axons* which convey equilibratory impulses centrally. Of these *one series* arises in the cells of the superior and lateral nuclei (Bechterew and Deiters) and passes in the medial longitudinal tract of the same and opposite sides to the effector nuclei of the ocular muscles. This connection establishes a reflex arc between receptor impulses arising in the vestibule and semicircular canals, and the effector nuclei of the ocular muscles, by means of which the eye muscles may react to equilibratory stimuli; the nerve mechanism is here protective to the individual, and enables him to turn the eyes at once to the cause of his loss of balance. In disease of the semicircular canals accompanied by nystagmus, it is further obvious that aberrant stimuli, transmitted over the receptor vestibular neurons, are poured in to the effector nuclei of the ocular muscles, overstimulating them, and so producing overaction of the cells, with the consequent tremulous movement of the eye muscles concerned.

A *second series* of secondary neurons over which equilibratory impulses are conveyed arises in the lateral nucleus of Deiters, proceeds downwards as the vestibulo-spinal tract in the anterior funiculus of the spinal cord of the same side, and establishes synaptic contact with all the final common effector neurons (lower motor neurons) of the spinal cord. In this way practically every muscle in the body is reflexly brought into play in the preservation of balance in response to receptor stimuli from the semicircular canals.

Those ascending branches of the vestibular neurons which

proceed directly to the cerebellum, without establishing synaptic contact with the vestibular nuclei, give off collaterals to the superior and lateral nuclei of Bechterew and Deiters, and then form a well-defined *vestibulo-cerebellar tract*, which finally terminates in the cortex of the cerebellum. This tract is joined by a few axons from the same nuclei (Bechterew and Deiters) which also pass to the cerebellum.

Lastly, there arise from the principal or medial vestibular nucleus a few axons which cross over to the opposite side and enter the reticular formation, in which they course as longitudinal fibres, though their precise termination is not clear. It does not appear that vestibular nerve neurons establish contact with the thalamus, a fact which appears to be in harmony with the totally unconscious mechanism of the vestibular apparatus.

The Vestibular Nuclei. As already stated, the vestibular nuclei are four in number—the principal or medial, the descending or spinal, the superior or Bechterew, and the lateral or Deiters. These nuclei are generally situated in the floor of the fourth ventricle in the vicinity of the lateral angle.

The *principal or medial vestibular nucleus* is the largest of the series, and lies subjacent to the acoustic or vestibular area; it belongs, therefore, partly to the medulla and partly to the pons.

The *descending or spinal vestibular nucleus* is associated mainly with the descending central branches of the vestibular nerve and lies on the medial or inner side of the restiform body. It extends downwards as far as the gracile nucleus of the medulla.

The *superior vestibular nucleus of Bechterew* lies in the lateral part of the floor of the fourth ventricle immediately lateral to the abducent nerve nucleus.

The *lateral vestibular nucleus of Deiters* lies almost exactly in the lateral angle of the fourth ventricle close to the restiform body.

Other Collections of Grey Matter within the Dorsal or Tegmental Pons. The other collections of grey matter, or discrete nuclei, which can be seen with low magnification,

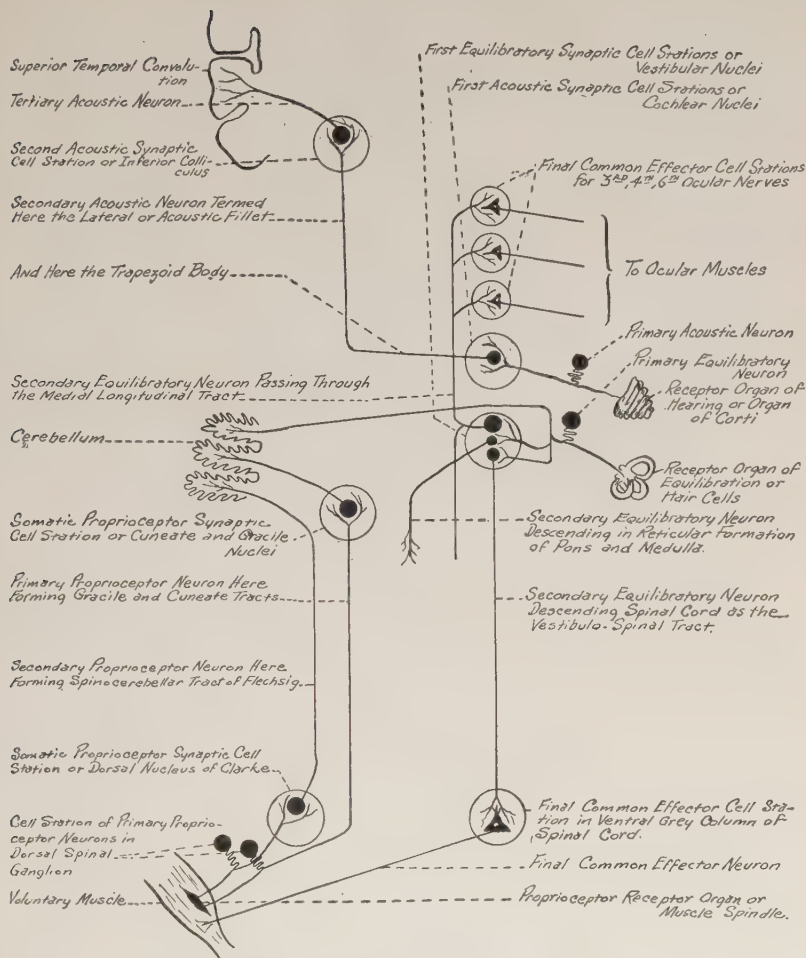


FIG. 53A.—A diagram illustrative of the proprioceptive (muscular and equilibratory) and exteroceptive (hearing) systems, to show that the same structural design underlies all receptor or sensory phenomena. See pages 100, 102, 104, 107, 139, 141, 205, 207, 230.

within the dorsal or tegmental pons are the nuclei of the trigeminal, abducent, and facial nerves. As these are, perhaps, of not quite the same clinical importance as those associated with the cochlear nerve of hearing and the vestibular nerve of equilibration, their further consideration may be deferred until the whole of the cerebral nerve connections are discussed in detail. (See Chapter XIX.)

White Tracts in the Dorsal or Tegmental Pons. The chief white tracts which traverse the dorsal or tegmental part of the pons may be summarised thus:

Ascending series.

The medial or sensory fillet, with which are now associated the spinal and trigeminal fillets.

The lateral or acoustic fillet.

The indirect, or ventral, spino-cerebellar tract of Gowers.

The superior cerebellar peduncles.

Descending series.

The rubro-spinal tract.

The vestibulo-spinal tract.

The tecto-spinal tract.

The olivo-spinal tract.

Ascending and descending series.

The medial longitudinal tract.

There are probably reticulo-spinal tracts passing from, or through, the pons to other levels. As most of these important tracts have been, or will be, fully considered, a few words of recapitulation here suffice.

The Medial or Sensory Fillet. The medial or sensory fillet, formed in the medulla, becomes, in the pons, very apparent as a distinct flattened mass or ribbon of white matter, which lies, at first, in the ventral part of the reticular formation, but at higher levels of the pons tends to become displaced to the lateral side, and makes its appearance on the exterior just above the fibres of the middle cerebellar peduncle or brachium pontis.

The Lateral or Acoustic Fillet. The lateral or acoustic fillet formed in the pons, as has just been described, by the



FIG. 54.—Drawing of a model of the brain stem of an infant showing the main tracts and nuclei of the effector cerebral nerves. (From: Morris, "Human Anatomy.")

cochlear nerve of hearing, first takes definite shape about the middle of the pons, where it lies lateral to the medial fillet. As it passes upwards it becomes displaced dorso-laterally, until it comes to lie on the outer or lateral side of the superior cerebellar peduncle (*brachium conjunctivum*).

The Indirect or Ventral Spino-Cerebellar Tract of Gowers.

The indirect or ventral spino-cerebellar tract of Gowers passes upwards from the spinal cord through the reticular formation of the medulla into the pons. At about the level of the exit of the trigeminal nerve the tract turns dorsally and enters the cerebellum through the anterior medullary velum, to terminate in the vermis. What remains of this tract continues to pass upwards through the pons and midbrain to establish contact with the superior colliculus and thalamus.

The Superior Cerebellar Peduncle (*Brachium Conjunctivum*). The superior cerebellar peduncle is an important cerebello-cerebral connection to be more fully described with the cerebellum. It assumes the form of a large and massive strand which runs from the dentate nucleus of the cerebellum to the red nucleus of the midbrain. As the superior cerebellar peduncle passes upwards, on either side of the fourth ventricle, it gradually sinks into the dorsal pons, until it becomes entirely submerged, and thus forms a prominent object in cross sections of the pons.

The Descending Tracts in the Dorsal or Tegmental Pons.

The main descending tracts found in the dorsal or tegmental pons are the rubro-spinal, vestibulo-spinal, tecto-spinal, and olivo-spinal tracts, none of which form easily recognisable tracts within this part of the pons, inasmuch as they are largely commingled with the grey matter of the reticular formation.

Ascending and Descending Tracts within the Dorsal or Tegmental Pons. The medial longitudinal tract is an important association tract, composed of axons passing in both directions, which is found in the midbrain, pons, and medulla; within the spinal cord it is continued onwards in the anterior fasciculus proprius. The tract is specially concerned with the

reflex control of the movements of head and eyes, and will be fully described with the midbrain. (See page 229.)

Functions of the Pons. If the evolutionary history of the pons be understood it will be clear that the *ventral or basilar pons* is a recent evolutionary addition to the pontine region consequent on the formation of a neopallial cerebral hemisphere, and is, therefore, largely conducting in character. The true functional part of the human pons is, as in almost all other animals, the old dorsal or tegmental pons.

The *dorsal pons* acts in a complementary capacity to many of the functions of the medulla. The tegmentum of both myelencephalon and metencephalon (medulla and pons) constitutes a common autonomous area essential to the regulation of the vital processes of life. The pons thus assists the medulla in the vital functions of respiration, phonation, deglutition and secretion, but takes no part in cardio-vascular control, or regulation of the alimentary canal, which are exclusively vagal functions of the medulla.

Amongst purely pontine functions are those exercised by the pons through the cerebral nerves, which have their nuclei within, or at all events, closely associated with, the pons. These comprise the ocular nerves, the effector part of the trigeminal nerve, and the important facial nerve. The pons also contributes, as has been seen, some important "relay" cell stations to the cochlear and vestibular nerves of hearing and equilibration.

Amongst the clinical reflexes negotiated through the pons are the mandibular, zygomatic, nasal, supra-orbital, conjunctival, lachrymal, auditory, and audito-oculo-gyric, for details of which a work on clinical medicine may be consulted. Doubtless many of these reflexes are concerned with the cells in the reticular formation. The audito-oculo-gyric reflex, for example, is the one which produces the sudden turning of the eyes in the direction of a sudden noise. Here the receptor limb of the neuron arc concerned is the cochlear nerve of hearing, the axons of which convey the impulse to the superior olivary nucleus, whence the impulse is transmitted by collat-

eral fibres to the abducent nerve nucleus. The effector limb of the arc extends from that nucleus to the lateral rectus muscle of the same side, and to the medial rectus muscle of the opposite side, by means of the medial longitudinal tract, and thus produces a reflex movement of lateral gaze in the direction of the sound.

Within the pons are at least two important *nerve decussations*. Of these the larger is the *decussation of the cerebro-ponto-cerebellar* fibres, which form the middle cerebellar peduncle, and serve as a crossed connection between the cerebral cortex and the lateral lobe of the cerebellum, for the synergic control of skilled movements.

A second pontine decussation is the *trapezoid decussation* of the cochlear nerve of hearing.

CHAPTER XVII

THE MIDBRAIN, ITS EVOLUTION AND NAKED EYE ANATOMY

The Evolutionary Primitive Parts of the Midbrain. From the evolutionary standpoint, the midbrain or mesencephalon may be said to be composed of three parts:

1. The primitive segmented tegmentum mesencephali.
2. The supra-segmental tectum mesencephali.
3. The recently added basis mesencephali.

The *primitive segmented tegmentum mesencephali*, represented in man by the tegmentum of the midbrain, is an upward continuation of the primitive parts of the pons and medulla, and is, therefore, the oldest part of the midbrain. It is segmented in character and is composed of two segments.

The *supra-segmental tectum mesencephali* is represented in man by the lamina quadrigemina with its two colliculi or quadrigeminal bodies. This part is a later evolutionary addition to the midbrain, and like the cerebellum and cerebrum is supra-segmental in type, as are all the most recent addi-

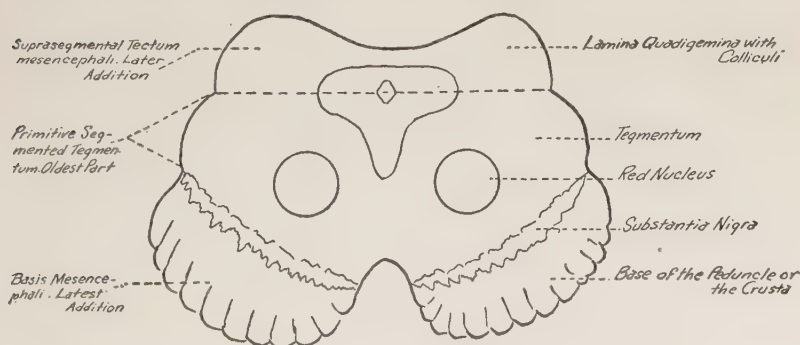


FIG. 55.—Diagram to illustrate the evolutionary primitive parts of the midbrain and their derivatives in man.

tions to the primitive neuraxis. Its evolutionary history is one of the most instructive episodes in the progress of the central nervous system.

The recently added *basis mesencephali* is an addition rendered necessary by the formation of a neopallial cerebral hemisphere. It corresponds, therefore, to the basal pons and the pyramids of the medulla, and subserves the same general function, that is, conduction from the cerebral cortex of effector impulses, and is represented in man by the base of the peduncle or the crusta.

It is thus clear that the human midbrain is composed of both segmented and supra-segmental parts, and constitutes an intermediate link between the more primitive segmented neuraxis and the more recently added supra-segmental portions. It is not, therefore, strictly accurate to regard the midbrain as only being a part of the brain stem. Everything on the cephalic side of the isthmus of the rhombencephalon is supra-segmental in type and cerebral in function. As thus defined there would be included in the cerebrum, a portion of the midbrain, the interbrain or diencephalon, and the cerebral hemispheres. Within this area are the primary receptor centres of the olfactory nerves, the receptor correlation areas for smell and sight, the primary effector (motor) and receptor (sensory) centres of the oculo-motor and trochlear nerves for movements of the eyes, and all the most important higher correlation centres of the brain itself. These higher correlation centres make up in the human brain by far the larger part of its substance, though in fishes the converse relation prevails, with the primary sensori-motor and the simpler correlation mechanism making up the larger part. (Herrick.) The great significance of this evolutionary differentiation between the segmented and supra-segmental portions of the neuraxis will be more fully discussed with the cerebellum, which is also supra-segmental in character.

The Evolution of the Midbrain. In many of the lower vertebrates, as, for example, some of the reptiles, the midbrain is one of the largest and most conspicuous portions of

the central nervous system, but in man it has become one of the smallest and least conspicuous divisions of the brain. This decrease in the size of the midbrain is due to a progressive retrogression of the functional activities of the mesencephalon, consequent on a transference of its functions to the more recently evolved neopallium. This shifting forwards of function from an older part of the neuraxis to a more recently added cephalic part is known as *telencephalisation*.

In its more primitive forms, a central nervous system is, as in the leech, a collection of neuronie reflex arcs, by means of which receptor impulses are translated into effector responses. There is no central apparatus for the advantageous combination, and storage of the incoming receptor impulses from the different segments of the body. Had the nervous system remained in all subsequent animal forms in this primitive uncombined form, the addition of new receptor organs or "senses," such as those for vision, smell, taste, hearing, equilibration, etc., would simply have resulted in new and additional non-correlated neuronie reflex arcs, and each new "sense" would thus have remained quite independent. With the addition of such senses it is essential that all should be fused into a common whole, and it is the chief duty of the "end-brain" to undertake the correlation of such senses. In the lower animal forms, where there is no neopallium and the midbrain is the "endbrain," the latter is naturally the correlating mechanism of the animal.

The midbrain was, therefore, originally a primordial organ or "endbrain" for the correlation of incoming receptor impulses, and there originally terminated in it three great and important receptor pathways, namely, those for visual, auditory, and somæsthetic sensibility. Impulses reaching the midbrain from the eyes, ears, skin, muscles, joints, bones and viscera were thus correlated in the midbrain to produce the most effective effector or motor responses.

Visual impressions from the retina originally terminated in that portion of the tectum mesencephali which has since become, in man, the superior colliculus. In birds this area

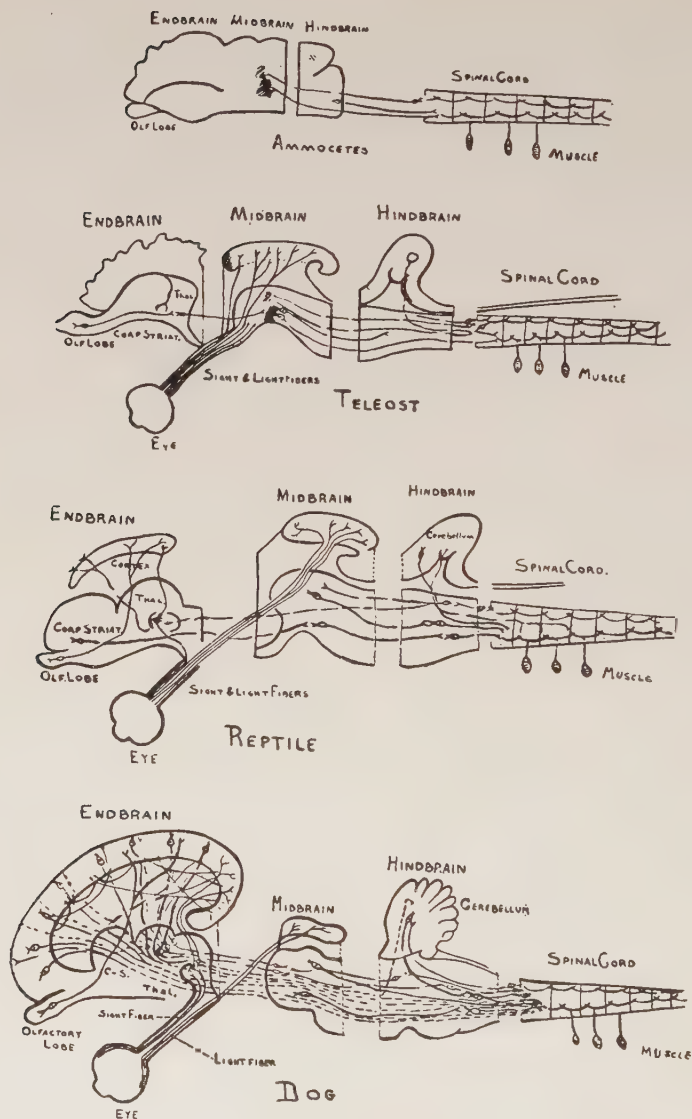


FIG. 56.—The diagram represents schematically the evolutionary process of telencephalisation, showing the gradual stepping-up process in the successive cephalad shifts from one level to another. (From: Tilney and Riley, "The Form and Functions of the Central Nervous System.")

is the "brain" of sight, contains many neurons, and thus becomes enlarged to form what is known as the *optic lobe*. By means of this greatly enlarged visual brain the homing pigeon is enabled to see its way over ranges far exceeding that of the human visual apparatus. In man, consequent on the addition of the neopallium, the centre for sight is transferred from the optic lobe (superior colliculus) to the occipital area of the cerebral hemisphere, and the former thus becomes reduced in size, and is retained functionally only as a light reflex area. It consequently follows that the superior collicular region of the midbrain has, in birds, a much more complex histological construction, with far more neurons, than has the corresponding area in man.

Auditory impressions similarly and originally terminated in that portion of the primitive tectum mesencephali which has since become the inferior colliculus, and a shifting forwards to the temporal region of the neopallium has occurred here, as with sight, with a consequent reduction in the size and structural complexity of the inferior colliculus, which, in man, becomes reduced to an acoustic reflex area.

Somæsthetic sensibility also terminated, primitively, in the expanded dorsal alar lamina of the midbrain. It, too, has become shifted forward to the neopallium.

In consequence, therefore, of the formation of a neopallial cerebral hemisphere and the transference thereto of functions originally undertaken by the midbrain, the latter has become, in man, much reduced in size and altogether over-shadowed by the cerebral hemispheres, and the colliculi (quadrigenimal bodies) altered from primary functional areas to secondary relay or reflex ones.

Naked Eye Anatomy of the Human Midbrain. The human midbrain or mesencephalon occupies the notch in the tentorium cerebelli, and connects the pons with the interbrain. Anatomically it consists of three parts, a dorsally situated lamina quadrigemina, comprising the two pairs of corpora quadrigemina or colliculi, ventrally placed cerebral peduncles or crura cerebri, and an intermediate tegmentum, which last

can only be seen on section. These three anatomical parts agree very closely with the three evolutionary parts of which the midbrain is built up, thus the anatomical lamina quadrigemina is the tectum mesencephali; the tegmentum persists unchanged, whilst the crura cerebri are the recently added basis mesencephali.

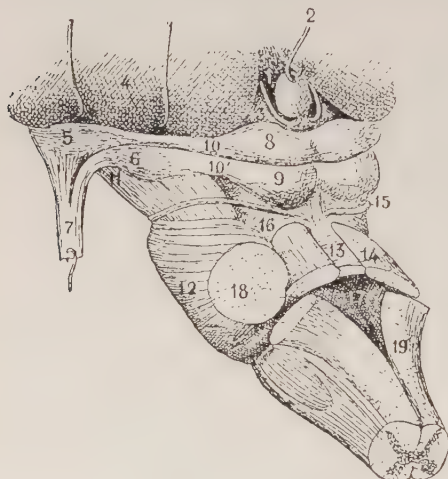


FIG. 57.—Mesencephalon and its relations. (Testut.) 1, third ventricle; 2, epiphysis or pineal gland; 3, trigonum habenulae; 4, posterior end of thalamus; 5, external; 6, internal geniculate bodies; 7, optic tract with its two roots; 8, anterior; 9, posterior corpora quadrigemina; 10, anterior; 11, posterior brachium of corpora quadrigemina; 12, pons; 13, valve of Vieussens; 14, superior cerebellar peduncles; 15, trochlear nerve; 16, lateral bundle of isthmus cerebri; 17, fourth ventricle; 18, middle cerebellar peduncles; 19, inferior cerebellar peduncles.

The Lamina Quadrigemina. The lamina quadrigemina forms the dorsal surface of the human mid-brain. It consists of four rounded elevations, the *quadrigeminal bodies* or the *colliculi*, separated from each other by a longitudinal and a transverse groove. When traced upwards the *longitudinal groove* expands slightly in order to form a triangular area in which the pineal body is lodged.

Of the two colliculi, the *superior* are the larger, and from them the *superior quadrigeminal brachia*

run laterally towards the lateral geniculate bodies. The superior quadrigeminal brachium forms the path by means of which optic fibres reach the superior colliculus and thus determines the reflex light pathway. In this course the superior quadrigeminal brachium passes between the pulvinar of the thalamus and the medial geniculate body.

The *inferior colliculi*, smaller than the superior, are similarly connected with the medial geniculate bodies by means of the inferior quadrigeminal brachia, and the connections

established are with the cochlear nerve of hearing. The medial geniculate body belongs to the interbrain, but has become displaced downwards on to the lateral aspect of the midbrain.

The Cerebral Peduncles or the Crura Cerebri. The two cerebral peduncles or the crura cerebri form the ventral part of the adult midbrain. As there seen they appear to commence at the upper border of the pons and diverge towards the cerebral hemispheres at an angle of from 30 to 45 degrees; just before they disappear in the hemispheres they are encircled by the optic tracts, and the space or depression bounded by the diverging peduncles and the optic chiasma and tracts is the *inter-peduncular fossa*. Within the confines of this space are the substantia perforata posterior through which small blood vessels pass; the mammillary bodies; and the tuber cinereum, infundibulum, and hypophysis.

The *ventral surface* of each cerebral peduncle is distinctly striated longitudinally, the striation being due to the longitudinally directed axons passing through it. These arise in the cerebral hemisphere and pass (a) to the spinal cord, where they form the cortico-spinal tracts, or (b) to the cerebellum by way of the pons and the middle cerebellar peduncles.

The *medial surface* of the cerebral peduncle is directed towards the inter-peduncular fossa, and upon it is the oculo-motor sulcus, from which the similarly named nerve emerges. This sulcus indicates the separation of the cerebral peduncle from the tegmentum.

The *lateral surface* of the cerebral peduncle is free in its lower two-thirds, and upon it, below the inferior quadrigeminal brachium, is a triangular depression—the *trigonum lemnisci*—which indicates upon the surface the position of the lateral or acoustic fillet in its course towards the inferior quadrigeminal brachium. Just in front of the triangle of the fillet is the *lateral sulcus of the midbrain*, which indicates the lateral extremity of the substantia nigra, just as the sulcus of the oculo-motor nerve marks its medial extremity. These two sulci thus separate the cerebral peduncle from the deeper tegmentum of the midbrain.

CHAPTER XVIII

THE MINUTE STRUCTURE OF THE MIDBRAIN

Structural Areas of the Midbrain. When transverse sections are made through the human midbrain its several evolutionary parts, as described in the previous chapter, can be readily recognised even with the naked eye. These three parts, which possess a structural and a functional significance, are as follows:

1. The *lamina quadrigemina*, on the dorsal side, comprises the colliculi or quadrigeminal bodies, and subserves important secondary functions concerned in the reflex activities of sight and hearing.

2. The *tegmentum* is an upward continuation of the corresponding parts of the pons and medulla, and within are found the primary effector or motor areas concerned in movements of the eyeballs.

3. The *cerebral peduncle* or the *crusta* contains the great descending tracts which run between the cerebral hemisphere on the one hand, and the pons, cerebellum, medulla, and spinal cord on the other. This part of the midbrain is, therefore, continuous with the basal pons and the pyramids of the medulla, and, like them, is only present in mammals with a neopallial cerebral hemisphere.

The Tegmentum of the Midbrain. The tegmentum is the oldest part of the midbrain. It is segmented in character and is an upward continuation of the tegmentum of the dorsal pons and medulla. Just as those parts are composed of reticular formation, so also is the tegmentum of the midbrain, and there is thus found in this part of the midbrain, an interlacement of longitudinal and transverse axons, in the interstices of which are minute masses of grey matter, and several larger discrete nuclei visible to the naked eye.

Grey Nuclei of the Tegmentum of the Midbrain. Within the grey matter of the tegmentum of the midbrain there are several discrete nuclei, namely, the dorsal nucleus of the raphe, the superior central nucleus, the ventral tegmental nucleus,



FIG. 58.—Section across mid-brain, through superior corpora quadrigemina. Magnified about $3\frac{1}{2}$ diameters. From a photograph. (Schäfer.) *Sy*, Sylvian aqueduct; *c.p.*, posterior commissure; *gl.pi.*, glandula pinealis; *c.q.a.*, grey matter of one of superior corpora quadrigemina; *c.g.m.*, corpus geniculatum mesiale; *c.g.l.*, corpus geniculatum laterale; *tr.opt.*, optic tract; *p.p.*, pes pedunculi; *p.l.b.*, posterior longitudinal bundle; *fl.*, upper fillet; *r.n.*, red nucleus; *n. III*, nucleus of 3rd nerve; *III*, issuing fibres of 3rd nerve; *l.p.p.*, locus perforatus posticus. (From: Luciani, "Human Physiology.")

the dorsal tegmental nucleus, and the red nucleus. Of these the first four are situated in the lower part of the midbrain and the upper part of the pons. The red nucleus is a conspicuous structural feature of the midbrain tegmentum and is of considerable functional importance.

The Red Nucleus. The red nucleus, so-called because in

the freshly cut section it has a reddish or pink appearance, is a large mass of nerve cells lying in the direct cerebral path of the fibres of the superior cerebellar peduncle (*brachium conjunctivum*), at about the centre of the tegmentum and opposite the superior colliculus. It can be followed in serial sections from the lower border of the superior colliculus into the hypothalamus.

The red nucleus *receives* fibres from the cerebellum by way of the superior cerebellar peduncles, the fibres of which encapsulate it, from the cerebral cortex, and from the striate body.

The red nucleus *gives off* axons which form the rubro-spinal tract which, after decussation, descends into the spinal cords. (See page 140.) Other axons pass from the red nucleus into the reticular formation and terminate in the nuclei of that formation and in the nucleus of the lateral fillet, whilst still others run to the thalamus, and so apparently form a link between the cerebellum and the thalamus.

The red nucleus is composed of two different sizes of nerve cells, the larger give origin to the axons of the rubro-spinal tract, the smaller to the *rubro-reticular tracts*. In man the latter are better developed than the former and are a phylogenetically newer part. This appears to suggest that in the lower animals the rubro-spinal tract is largely a tract through which the cerebellum influences the motor activities of the medulla and cord. In man this function is retained, but is more closely linked up with the pons by way of the rubro-reticular tracts. The chief functional significance of the red nucleus would thus appear to be that it brings the cerebellum, the striate body, and to a lesser extent, the cerebral cortex to bear on the control of the voluntary somatic muscles.

The Longitudinal Tracts of the Tegmentum of the Mid-brain. The chief longitudinal white tracts which traverse the tegmentum of the midbrain are naturally those which have already been discussed, namely, the sensory fillet, the acoustic fillet, part of the tract of Gowers, the medial longitudinal tract, and one additional one, the superior cerebellar peduncles coming in from the cerebellum. Amongst the

descending tracts which traverse the tegmentum of the mid-brain or arise therein are the rubro-spinal tract, the tecto-spinal tract, the fasciculus retroflexus and the doubtful tecto-pontine tract.

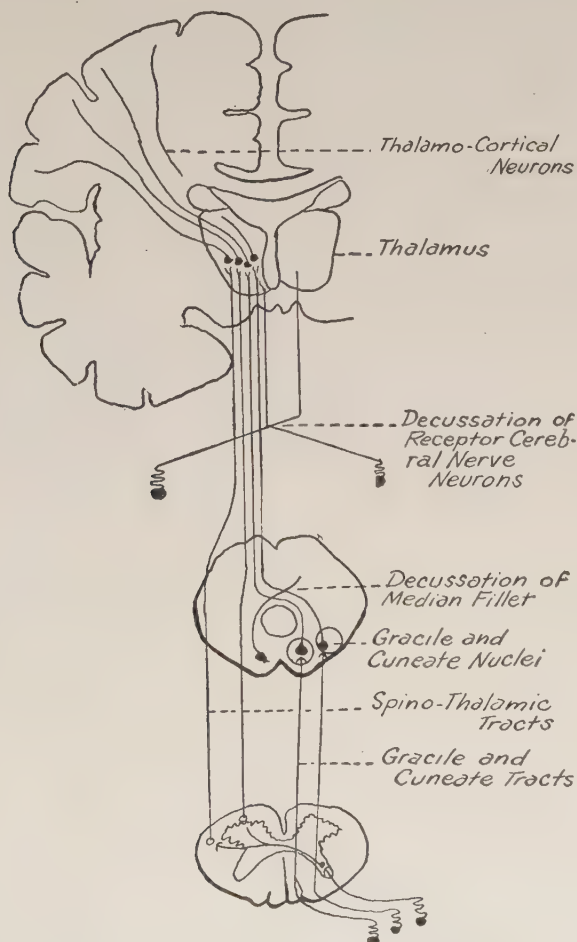


FIG. 59.—Diagram to show the accessions to the median fillet in its passage through the brain stem. See pages 105, 118, 179, 181, 227.

The *medial* or *sensory fillet* traverses the whole length of the tegmentum of the midbrain, in the lower part of which it assumes the form of a more or less flattened band, which

lies on the lateral side of the decussating fibres of the superior cerebellar peduncles. It here forms an acute angle with the more laterally placed lateral acoustic fillet, and takes part in the surface formation of the triangle of the fillet. When traced upwards the medial fillet becomes pushed dorso-laterally by the red nucleus.

In its upward path to the thalamus the medial or sensory

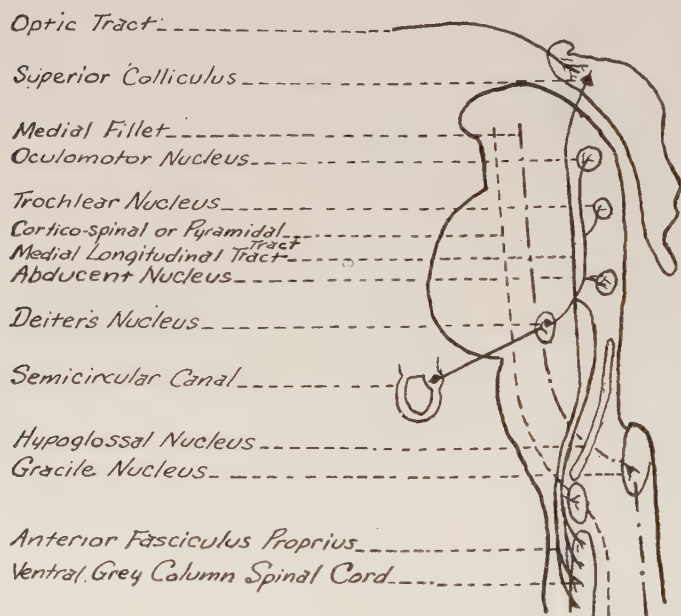


FIG. 60A.—Diagram to illustrate the medial longitudinal tract in profile. See pages 125, 214, 229, 251.

fillet becomes progressively larger because it is joined by the spino-thalamic tracts from the spinal cord, and the central tracts of the receptor cerebral nerves of which the central receptor tract of the trigeminal nerve is but an outlying and additional part.

The *lateral* or *acoustic fillet*, on entering the tegmentum of the midbrain, forms together with the medial or sensory fillet, a broad, curved band, which occupies the ventral and lateral

parts of the tegmentum. It ascends through the tegmentum of the midbrain with a dorsal inclination, and its axons terminate in the inferior colliculi of the same and opposite sides; a few of the axons, however, do not terminate in the inferior colliculus, but pass to the medial geniculate body through the inferior quadrigeminal brachium, which they form.

As regards the *ventral* or *indirect spino-cerebellar tract* of Gowers, it has been pointed out that all its fibres do not enter

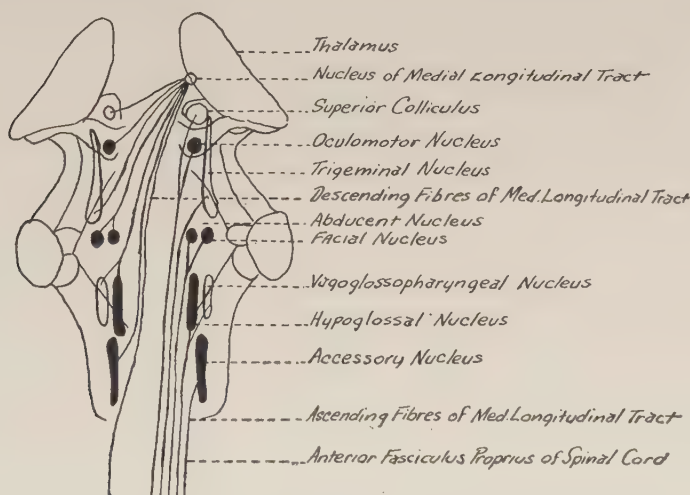


FIG. 60B.—Diagram to illustrate the medial longitudinal tract from behind.

the cerebellum. A few of them are continued through the pons and the dorso-lateral part of the tegmentum of the midbrain to the superior colliculus and hypothalamus. The *cerebellar portion* of this tract pursues a short course along the lateral margin of the tegmentum of the midbrain to enter the cerebellum in the manner previously indicated.

The Medial Longitudinal Tract. It has already been seen that the anterior fasciculus proprius of the spinal cord becomes continuous, in the brain stem, with an important association

tract, the medial longitudinal tract, and that its position becomes altered from the ventral to the dorsal sides by the decussations of the pyramids and fillets. In the midbrain the medial longitudinal tract is more conspicuous than in any other part of the neuraxis, and is hence best discussed here.

Consequent on the decussations referred to the medial longitudinal tract is always found in the brain stem in the same position, namely, on the dorsal side and close to the median raphe in intimate association with the grey matter around the cerebral aqueduct of Sylvius, in which are placed the effector nuclei of origin of the ocular nerves. From these, and other associations, the medial longitudinal tract derives its chief functional significance, which is that the tract is the chief factor in the reflex control of the movements of the eyes, and especially in the co-ordination of these movements with those of the head and neck and the balancing of the body.

A large proportion of the axons of the medial longitudinal tract are derived from *the nerve cells of the lateral vestibular nucleus (Deiters)*. From this origin the axons pass transversely through the reticular formation to the medial longitudinal tract of the same and opposite sides, on entering which they divide into ascending and descending branches. The former pass upwards to establish synaptic contact with the effector nuclei of the oculo-motor, trochlear, and abducent nerves, and thus the eyes are made to respond to proprioceptive impulses arising in the semicircular canals. The latter descend to establish a similar synaptic contact with the effector nucleus of the spinal accessory nerve, and with the effector cells of the ventral grey columns of the spinal cord. The muscles of the head and body are thus brought directly under the control of proprioceptive impulses from a like source.

Other axons found in the medial longitudinal tract arise from cells scattered through the reticular formation of the midbrain, pons, and medulla; from the cells of the recipient nuclei of some of the cerebral nerves, particularly the trigeminal, and also from a collection of nerve cells situated in the

hypothalamus (interstitial nucleus of Cajal or the nucleus of the medial longitudinal tract).

The medial longitudinal tract thus contains fibres coursing in both directions, and whilst it is continually losing fibres by termination, it is continually being reinforced, and so maintains a practically uniform bulk. Any lesion of the tract never results, therefore, in its total degeneration. The tract is obviously an important central association between the vestibular nerve of equilibration, the ocular muscle nerves, and most of the effector nerves of the head and neck. It thus plays an important part in the co-ordination of the mechanism for the balancing of the body in space, and brings the nuclei of the ocular nerves under the direct influence of the equilibratory apparatus. Its importance is still further shown by the fact that its axons acquire their medullary sheaths at a very early stage, in fact, as soon as the roots of the nerves themselves. The tract appears to be present in nearly all vertebrates, and in some is even better marked than in mammals. It is small in the mole, and large in reptiles and amphibia.

The medial longitudinal tract is thus composed very largely of internuncial neurons forming parts of reflex arcs concerned in the regulation of the combined movements of the head and eyes in response to proprioceptive impulses generated in the semicircular canals by every movement of the head. Aberrant stimuli, or too strong stimuli, arising in the semicircular canals, or the vestibular nuclei, may thus abnormally stimulate the effector nuclei of the ocular nerves and so produce those oscillating movements of the ocular muscles known clinically as nystagmus.

The Superior Cerebellar Peduncles or the Brachia Conjunctiva. It has already been seen that the superior cerebellar peduncles or the brachia conjunctiva pass from the cerebellum towards the cerebrum. They converge upon the pons from the dorsal side, and as they ascend they sink deeper and deeper into the substance of this part of the neuraxis. When they gain the level of the inferior colliculi of the midbrain they have become completely submerged and are deeply

placed in the tegmentum and now commence to decussate. Having decussated the axons ascend and end either in the red nucleus or the thalamus. The connections established by the superior cerebellar peduncles will be more fully discussed with the cerebellum. (See page 286.) The decussation of the superior cerebellar peduncles forms, however, a prominent feature of transverse sections made through the midbrain at the level of the inferior colliculus.

The Transverse Fibres of the Tegmentum of the Midbrain. The chief collections of transverse axons in the tegmentum of the midbrain are those formed by the decussations of the superior cerebellar peduncles, just mentioned, the dorsal tegmental decussation, and the ventral tegmental decussation.

The *dorsal tegmental decussation* or the *fountain decussation of Meynert* is composed of fibres which arise in the superior colliculi, decussate, and then descend in the dorsal part of the raphe as the tecto-bulbar and tecto-spinal tracts. The connection would thus appear to be a contra-lateral one between the lower visual centres and the effector cells of the cerebral and spinal effector nerves.

The *ventral tegmental decussation of Forel* is the decussation formed by the axons of the rubro-spinal tract just below the red nucleus.

The Lamina Quadrigemina of the Midbrain. The lamina quadrigemina is an evolutionary recent supra-segmental addition to the older tegmentum. It lies on the dorsal side of the latter and contains the colliculi. The lamina quadrigemina, originally largely associated with sight, has become reduced in size and functional importance, on account of the transference of the visual area to the occipital region of the neopallial cerebral hemisphere.

The lamina quadrigemina roofs in, on the dorsal side, the midbrain region, hence the name frequently applied to it, of *tectum mesencephali*. "The tectum mesencephali is in all vertebrates an end-station for the optic tracts. In the lower vertebrates there are but two elevations in the roof, the *optic lobes* or *corpora bigemina*, and these, which correspond in a

general way to the *superior colliculi*, are visual centres. In mammals the development of a spirally wound cochlea is associated with the appearance of two additional elevations, the *inferior colliculi*, within which many of the fibres of the central auditory path terminate. The entire tectum receives fibres from the spinal cord and medulla oblongata and sends other fibres back to them; it also receives fibres from the cerebral cortex. It contains important reflex centres, those in the superior colliculus being dominated by visual, those in the inferior colliculus by auditory, impulses." (Ranson.)

The Inferior Colliculus or the Inferior Quadrigeminal Body. Each inferior colliculus contains, in addition to the laminated grey matter of the tectum mesencephali, a large grey oval mass, known as the *nucleus of the inferior colliculus*. This nucleus is encapsulated by white substance, and is traversed by an intricate interlacement of medullated axons, largely derived from the lateral or acoustic fillet. These axons lie at first on the lateral side of the nucleus, and thereafter terminate in its cells, as also in those of the medial geniculate body, which they reach by passing through the inferior quadrigeminal brachium, whilst others again pass up to the superior colliculus. A *second series* of fibres from the lateral acoustic fillet is carried round the dorsal side of the nucleus of the inferior colliculus, and decussates with those of the opposite side so as to encapsulate it; a *third series* of axons from the lateral or acoustic fillet passes on the ventral side of the nucleus, and marks it off from the grey central matter around the cerebral aqueduct of Sylvius. The inferior colliculus and the medial geniculate body are thus intimately associated with the sense of hearing, and serve as subcortical reflex areas for that sense. Both the inferior colliculi are connected together across the median plane by commissural decussating fibres.

The axons of the lateral or acoustic fillet thus convey auditory impulses from the recipient nuclei of the cochlear nerve to the inferior colliculi and medial geniculate bodies. Those which terminate in the inferior colliculi are concerned with

reflexes in response to sound. Those which pass to the medial geniculate bodies are there relayed and pass on to the acoustic area in the temporal cortex. The inferior quadrigeminal brachia also contain a few axons of cortical origin, chiefly from the temporal lobe, which terminate in the inferior colliculus.

The Superior Colliculus or the Superior Quadrigeminal Body. The superior colliculus presents a more complicated structure than the inferior, and is composed, from the surface inwards, of four superimposed nerve strata. On the exterior there is a thin white layer, termed the *stratum zonale*, composed of transversely coursing medullated axons. It is generally assumed that these axons are derived from the optic tract, but as they do not undergo degeneration in experimental lesion of the optic tracts and nerves, the belief is probably erroneous.

The third or *optic layer* is a mixed white and grey layer which contains few white fibres, but many nerve cells, and is hence known as the *grey stratum*. These cells are probably those of the tecto-spinal tracts.

The third or *optic layer* is a mixed white and grey layer and contains many medullated axons, most of which are derived from the optic tract through the superior quadrigeminal brachium, and establish synaptic contact with the cells of the grey layer. Other axons found in this layer are derived from the visual occipital area of the cerebral cortex. According to Cajal these cortical fibres end in the next layer of the superior colliculus, that is, the layer of the fillet.

The fourth or most internal layer of the superior colliculus is a mixed white and grey layer and is known as the *layer of the fillet*, because some of the axons of the lateral or acoustic fillet terminate herein.

Some of the fibres of the lateral spino-thalamic tracts appear to terminate in the superior colliculus. These fibres, occasionally designated the *spino-tectal tracts*, arise in cells in the dorsal grey columns of the spinal cord, pass upwards in the closest association with the lateral spino-thalamic tracts,

and enter the tectum mesencephali with the terminal part of the lateral or acoustic fillet.

The superior colliculi and lateral geniculate bodies bear, therefore, the same general relationship functionally, to the optic nerve fibres from the retina, and the visual cortical area in the occipital region, as do the inferior colliculi and medial geniculate bodies to the cochlear nerve of hearing and the cortical centre for hearing in the temporal lobe.

Like the inferior colliculi, the superior colliculi are connected together across the median line, by decussating commissural fibres.

Tracts Arising within the Tectum Mesencephali. Within the roof of the midbrain arise certain small tracts, the majority of which have their cell stations in the superior colliculi. Of these the most important is the *tecto-spinal tract* or the *ventral longitudinal bundle*. This tract arises in the superior colliculus, descends in close relationship with the medial longitudinal tract, decussates in the median raphe of the tegmentum of the midbrain, forming there the dorsal tegmental decussation of Meynert. After decussation the tract descends through the pons and medulla to the spinal cord, where it establishes synaptic contact with the cells of the final common effector pathway, and so brings optic impulses to bear on the control of voluntary muscles.

A *tecto-bulbar* or *tecto-pontine tract* is said to arise in the inferior colliculus and to pass downwards to end in the pons or medulla.

The Cerebral Aqueduct and the Central Grey Matter. Between the tectum mesencephali and the tegmentum of the midbrain are found the cerebral aqueduct and the central grey matter.

The cerebral aqueduct of Sylvius is an upward continuation of the fourth ventricle and forms part of the ventricular system of the brain and spinal cord. The closure of the fourth ventricle is brought about, in this region, by the invasion of the primitive roof of the midbrain, by optic nerve neurons and the formation there of a supra-segmental addition to the

neuraxis. The result is that the central canal which opens out in the medulla for the reasons set out on page 172 now become closed again, and so produces the cerebral aqueduct of Sylvius.

The *cerebral aqueduct of Sylvius* is the midbrain portion of the cavity of the primitive neural tube. In the adult it forms a small canal, about 2 cm. in length, which traverses the midbrain and connects together the fourth and third ventricles. It is lined by columnar ciliated epithelium, and is surrounded by a thick layer of grey matter—the central grey stratum.

The *central grey stratum* is the thick layer of grey matter which, as just stated, surrounds the cerebral aqueduct, and is continuous with the grey matter spread out on the floor of the fourth ventricle, and with the grey matter on the floor and sides of the third ventricle. It is almost entirely composed of nerve cells and contains relatively few medullated axons, hence it is almost colourless in Weigert preparations. The nerve cells found within the central grey stratum are either diffused throughout its extent, or are collected together into well-defined discrete nuclei, of which three may be recognised—the nucleus of the oculo-motor nerve, the nucleus of the trochlear nerve, and the nucleus of the mesencephalic root of the trigeminal nerve. These nuclei may be more fittingly described with the nerves to which they give origin. (See Chapter XIX.)

The Cerebral Peduncle or the Crusta of the Midbrain. The cerebral peduncle of the midbrain, or the crusta, is the latest evolutionary addition to the midbrain, and is only found in mammals with a neopallial cerebral hemisphere. It is thus a continuity of the basal pons and the pyramids of the medulla.

As seen in transverse section the *base of the peduncle* is somewhat crescentic in outline, and is separated from its fellow of the opposite side. It is bounded dorsally by a layer of deeply pigmented cells, termed the *substantia nigra*, which separates it from the tegmentum of the midbrain, and projects into it with an irregular convex border.

Structurally, the base of the peduncle is entirely composed of longitudinally directed medullated axons which pass from the internal capsule, through the base of the peduncle, into the longitudinal bundles of the pons.

The *middle three-fifths* of the base of the peduncle is occupied by the axons of the cortico-spinal tracts, which arise in the effector cells of the "motor" area of the cerebral cortex, traverse the corona radiata and the middle part of the internal capsule of the cerebral hemisphere, to reach their present position. In their descent these fibres give off collaterals to the nuclei pontis. Those of these fibres which are destined to proceed to the nuclei of the effector cerebral nerves tend, at this level, to separate themselves off from those axons proceeding to the cortico-spinal tracts of the spinal cord, and are here sometimes designated the *cortico-bulbar tracts*. They lie at either end of the main group.

The axons in the *medial* and *lateral fifths* of the base of the peduncle form the cerebro-pontine fibres already referred to. (See page 202.) The medial fifth is composed of fronto-pontine fibres, and the lateral fifth of other cerebro-pontine fibres. Both series form parts of the cerebro-ponto-cerebellar connections.

Substantia Nigra. The substantia nigra is a mass of deeply pigmented cells interposed between the tegmentum and the base of the peduncle. It is found only in the midbrain region and extends from the pons to the subthalamie tegmental region. Its functions, connections, and morphology, are not understood, though it is stated to undergo atrophy as a result of lesions of the "motor" cerebral cortex. It is also stated that the substantia nigra receives both crossed and uncrossed fibres from the striate body, and collateral branches from some of the fibres traversing the base of the peduncle. The axons of the cells of the substantia nigra are believed to pass into the tegmentum of the midbrain, though their real destination is still uncertain.

Interpeduncular Ganglion. The interpeduncular ganglion is a small mass of nerve cells found in the median

plane between the bases of the peduncles. It appears to be best developed in animals with an acute sense of smell, and within it terminate fibres (the fasciculus retroflexus) which are derived from the habenular nucleus of the epithalamus.

Functions of the Midbrain. The general functions of the midbrain differ from those of the pons and medulla, inasmuch as its immediate influences are chiefly concerned with somatic functions, whereas the pons and medulla are more particularly visceral in character.

The brief account of the evolution of the midbrain throws

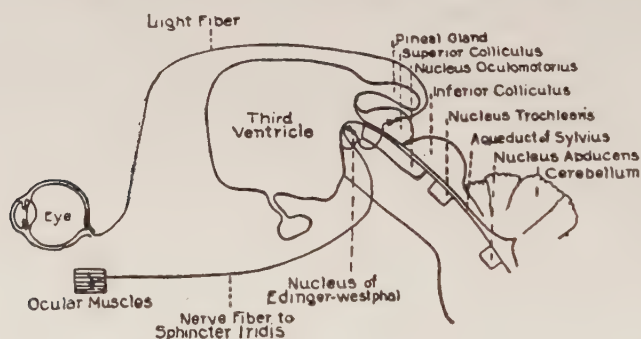


FIG. 61.—Diagram the pupillary light reflex. (From: Tilney and Riley, "The Form and Functions of the Central Nervous System.")

light on the functions of the tectum or roof of the midbrain. The *superior colliculus*, freed from its original functions of vision, becomes, in man, an important cell station for the accomplishment of some of those important reflexes termed *light reflexes*. Amongst these are the direct light reflex, the consensual light reflex, the accommodation and convergence reflexes, and the oculo-cephalo-gyric reflex. In the main, therefore, the superior colliculus serves, in man, for the relatively simple reflex correlations connected with the visual sense. All of its originally visual functions have been transferred to the occipital cerebral cortex.

Of these light reflexes two, the *direct light* and *accommodation* reflexes, are of very special importance, because they are

visual cortex appropriate impulses cause contraction of both pupils, in order to concentrate the visual impressions from the near object upon the macula.

It will be observed that between the central pathways of these two reflexes there are important differences. The *direct light reflex* is a short neuronie arc to the superior colliculus, and does not involve the cerebral cortex. The *accommodation reflex* is a long neuronie arc, which passes to the cerebral cortex through the lateral geniculate body.

Within the midbrain there also occur those numerous central connections between the nuclei of origin of the effector ocular nerves, which are so essential for the harmonious movements of the eyeballs, as well as those between these nuclei and other closely correlated ones. By means of these connections, there are also provided the auditory oculo-motor, the conjunctival oculo-motor, the inter-ocular, oculo-facial, and vestibulo-ocular associated reflexes.

CHAPTER XIX

THE CENTRAL CONNECTIONS OF THE CEREBRAL NERVES

Anatomical Classification. The well known anatomical classification of the cranial or cerebral nerves into twelve pairs, olfactory, optic, oculo-motor, trochlear, trigeminal, abducent, facial, acoustic, glosso-pharyngeal, vagus, accessory, and hypoglossal is out of date and somewhat misleading. Introduced many years ago it fails to take cognisance of newer facts, such as the cochlear nerve of hearing and the vestibular nerve of equilibration; makes no mention of the *nervus terminalis*, and as it is a naked eye classification only, the minute construction of the nerves is naturally ignored. Functionally it is the last which is today important.

Minute Structure of the Cerebral Nerves. As the cerebral nerves fulfil the same functions for the head as the spinal nerves do for the trunk and limbs it follows that they contain the same types of neurons, namely, somatic and visceral receptor, and somatic and visceral effector, but in addition the head contains some important extero-ceptive senses, such as sight, hearing, etc., which are not present in the trunk, so that some, at least, of the cerebral nerves must contain additional and special types of neurons not present in spinal nerves. Amongst these are special somatic receptor neurons, such as the extero-ceptive cochlear neurons of hearing, and the proprio-ceptive vestibular neurons of equilibration; special visceral receptor neurons, such as those from the sense of taste; and special visceral effector neurons destined for the supply of the striated musculature derived from the branchial arches, as distinguished from the general skeletal musculature developed from the myotomes, though these last are often classified as somatic.

It thus follows that seven types of neurons may be described as passing through the cerebral nerves, although no one cerebral nerve contains them all.

General Arrangement of the Cerebral Nerve Cell Stations.

It has already been seen that the lateral wall of the developing neural tube soon differentiates into an *alar plate* which is receptor in function, and a *basal plate* which is effector, and that the two are partially separated by the limiting sulcus. This general arrangement holds good in all the cerebral vesicles which give origin to the cerebral nerves, but in the rhombencephalon, consequent on the changed position of the grey and white matter, both plates come to lie in the floor of the fourth ventricle and the basal or effector plate is the more medial of the two. It thus follows that the nuclei of origin of the effector cerebral nerves are more medially situated than the receptor. In the cases of the cerebral nerves, just as with the spinal nerves, the basal plate becomes differentiated into a somatic and a splanchnic column of effector nuclei, whilst the alar plate similarly divides into a somatic and splanchnic column of receptor nuclei.

The *somatic receptor column* eventually subdivides into two—one within which terminate extero-receptive fibres from the skin of the head and hence termed the *general* somatic receptor column, and one in which terminate the special somatic sense organs of hearing and equilibration, and thus termed the *special* somatic receptor column.

The *visceral receptor column* is represented by the nucleus of the solitary tract, within which terminate both the *general* visceral receptor neurons from mucous membranes, as well as the *special* visceral receptors of taste.

The *somatic effector column* includes the effector nuclei of all those cerebral nerves which supply the striated musculature developed from the myotomes, that is, the oculo-motor, trochlear, and abducent nerves for the extrinsic muscles of the eye, and the hypoglossal for the muscles of the tongue.

The *visceral effector column* subdivides into two, general and special. The *general* visceral effector column comprises those nuclei which preside over the innervation of the invol-

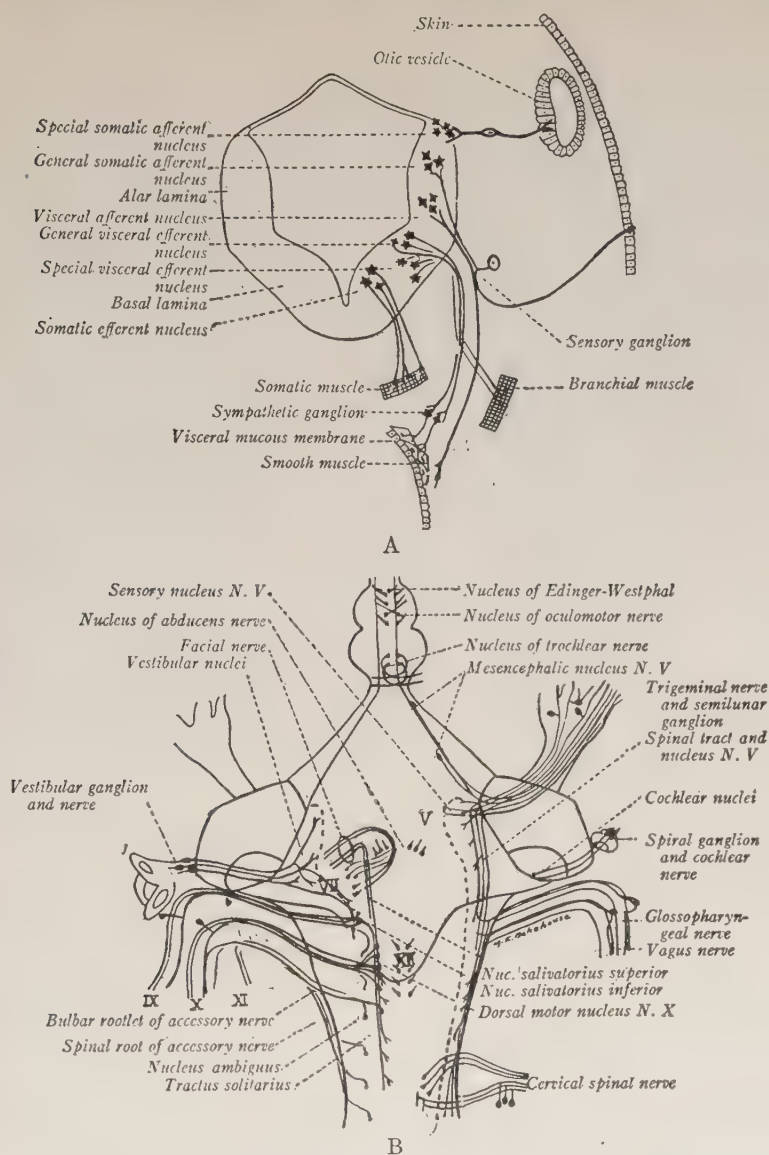


FIG. 63.—Two diagrams showing the origin, course, and termination of the functional components of the cranial nerves. (A), shows the locations of the several functional cell columns in a section through the medulla oblongata of a human embryo and the peripheral terminations of the several varieties of fibres. (B), dorsal view of the human brain stem, showing the location of the nuclei and the intramedullary course of the fibres of the cranial nerves. (From: Ranson, "The Anatomy of the Nervous System.")

untary muscle of the head as well as its glandular tissue, and the dorsal effector nucleus of the vagus nerve is the chief example. The *special* visceral column comprises a ventrolateral group of nuclei which give off special visceral effector fibres to the striated visceral or branchial musculature, and includes the nucleus ambiguus and the effector nuclei of the fifth and seventh nerves.

The General Somatic Receptor Nuclei. The general somatic receptor nuclei are relay cell stations for receptor neurons transmitting exteroceptive impulses from the skin and ectodermal mucous membrane of the head by way of the trigeminal nerve. The neurons of the trigeminal nerve are of the usual bipolar receptor character with the cell station in the semi-lunar or Gasserian ganglion. The peripheral processes of these neurons form the branches of the trigeminal nerve, whilst the central processes enter the pons and therein divide into short ascending and long descending divisions. These establish synaptic contact with the neurons which have their cell stations in the general somatic column, hence these nuclei are often termed the "recipient nuclei of termination" of the trigeminal nerve—a misleading term—because they are, in reality, the cell stations of the *secondary* series of neurons over which receptor trigeminal nerve impulses are conveyed centrally.

The short *ascending* central processes of the primary trigeminal nerve neurons arborise around the cells of the *upper or main sensory nucleus of the trigeminal nerve*, which is merely the enlarged cephalic end of the substantia gelatinosa of the spinal cord. This nucleus is found at the middle of the pons in the lateral part of the reticular formation and immediately subjacent to the submerged border of the superior cerebellar peduncle.

The longer *descending* central processes of the primary trigeminal nerve neurons form, in their descent, the *spinal tract*, which is well marked in all transverse sections of the medulla. This tract diminishes in size as it is traced downwards, owing to the rapid termination of its axons around the cells of the

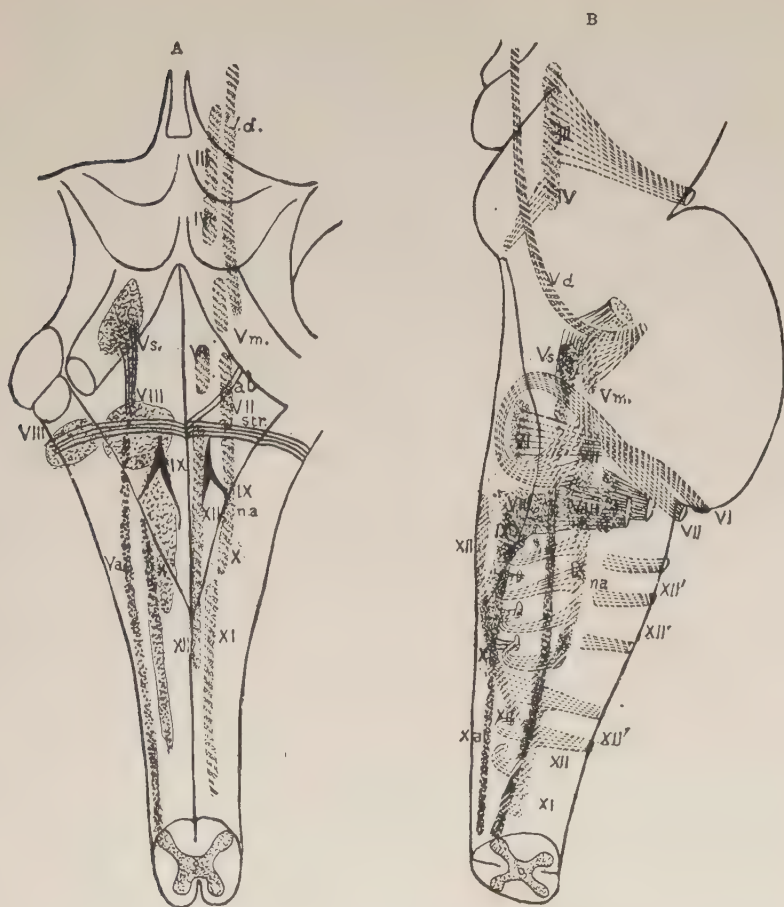


Fig. 64.—Diagram to show situation of chief nerve-nuclei and terminations of cranial nerves in medulla oblongata and pons near floor of fourth ventricle. A, from behind; B, profile view of right half, the medulla and pons being supposed to be transparent. In A the motor nuclei are represented on right side only, the sensory on the left. III, IV, oculomotor and trochlear nucleus; *Vd*, descending root of 5th nerve; *Vs*, so-called sensory nucleus of 5th; *Vm*, motor nucleus of 5th; *VI*, nucleus of abducens; VII, nucleus of facial; *n*VII, root of facial curving round abducens nucleus; VIII, inner or dorsal nucleus of auditory; VIII', outer or ventral nucleus of auditory; IX, X, vago-glosso-pharyngeal nucleus; *na*, nucleus ambiguus, accessory or efferent vago-glosso-pharyngeal nucleus; XI, nucleus of spinal accessory; XII, nucleus or hypoglossal; XII, issuing roots of hypoglossal. (From: Luciani, "Human Physiology.")

nucleus of the spinal tract. This nucleus is, at first, deeply situated under cover of the restiform body, but when traced downwards it approaches the surface, and covered by the axons of the spinal tract, that is, the axons which are terminating around its cells, forms the tuberculum cinereum, and becomes continuous with the substantia gelatinosa of the spinal cord. It is thus obvious that throughout the whole length of the spinal cord, medulla, and pons, there is a long column of grey matter—the substantia gelatinosa, the nucleus of the spinal tract of the trigeminal nerve, and the upper or main sensory nucleus of the same nerve—around the cells of which terminate primary neurons conveying extero-ceptive impulses from the skin of the trunk, limbs, and head.

The main sensory nucleus and the nucleus of the spinal tract constitute the cell stations of the *secondary* neurons over which trigeminal nerve impulses are conveyed. The axons arising in these cells enter the reticular formation of the regions in which they are found and there form longitudinal bundles which give off collateral branches to the effector nuclei of the brain stem, so that in this way there are formed numerous reflex arcs. Most of the axons cross over to the opposite side in the ventral part of the reticular formation, and turning upwards, join the medial fillet, and thus reach the thalamus. A smaller proportion of the axons remain on the same side and assume a more dorsal position not far from the floor of the fourth ventricle and the central grey matter of the cerebral aqueduct and it is probably these axons which establish reflex arcs with the effector ocular nerves, but in any case, it is clear that the secondary neurons over which trigeminal nerve impulses are conveyed not only convey those impulses towards the cerebral cortex by way of the thalamus, but also establish numerous alternate and reflex arcs.

The central path of *proprio-ceptive* impulses through the cerebral nerves is not so well known as the extero-ceptive impulses from the skin. That such impulses arise in the muscles of mastication and the extrinsic muscles of the eye is

certain, but their central path is not, in all instances, definitely established.

The Special Somatic Receptor Column. In this column are the nuclei of the cochlear nerve of hearing and the vestibular nerve of equilibration, the former conveying exteroceptive impulses of sound and the latter proprioceptive impulses from the semicircular canals. The important central connections established by these nerves have already been described. (See pages 205 and 207.)

The General Visceral Receptor Column. To the general visceral receptor column pass those primary neurons of the glosso-pharyngeal and vagus nerves which convey receptor impulses from the dorsal third of the tongue, and from the pharynx, larynx, trachea, œsophagus, and thoracic and abdominal viscera. As such neurons have a termination which is common to them, as well as to the special visceral receptors, that termination may be discussed with the latter.

The Special Visceral Receptor Column. To the special visceral receptor column pass those *primary* neurons which transmit impulses of taste, and have a termination common to them and the general visceral receptors.

Excluding the sense of smell, which has undergone much evolutionary change, all general and special visceral receptor neurons from the head pass through the facial, glosso-pharyngeal, and vagus nerves, though the majority of the special visceral receptors of taste course through the facial and glosso-pharyngeal, with only a few from the epiglottis through the vagus. The central processes of all the general and special visceral neurons, whether contained in the facial, glosso-pharyngeal, or vagus nerves, on entering the neuraxis, are collected together to form a recognisable microscopic object, the *solitary tract*, within which they descend for varying distances. In their passage along this tract, the axons terminate by arborising around the cells of the secondary neurons, which are collected together to form the *nucleus of the solitary tract*. This nucleus is a long slender nucleus which extends through the whole length of the medulla, where it lies on the imme-

diate lateral side of the dorsal effector nucleus of the vagus and some little distance from the floor of the fourth ventricle. The axons from the several nerves terminate within the nucleus in the same order from above downwards, so that the upper end is chiefly concerned with taste, and the lower end with vagal activities. According to Cajal some of the vagal neurons cross over to the opposite side and there terminate in

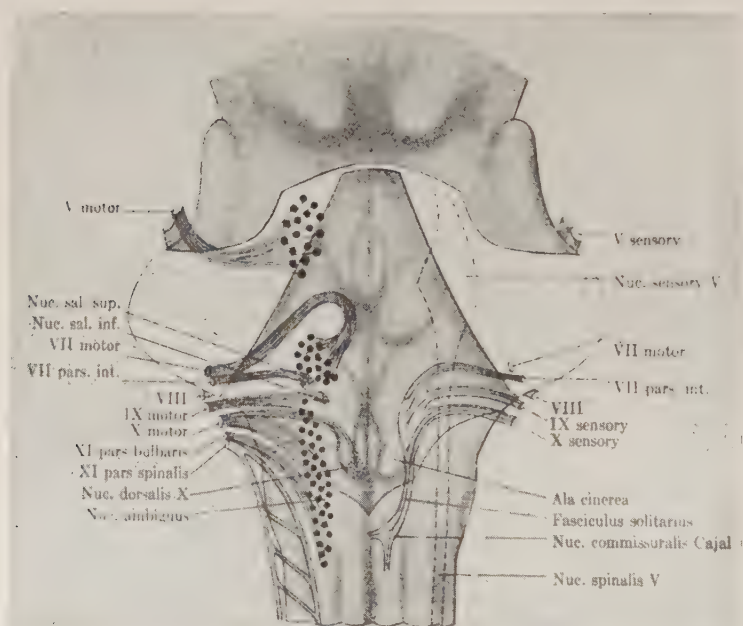


FIG. 65.—A diagram of visceral receptor and effector connections in the medulla oblongata. The receptor roots and centers are indicated on the right side, the effector on the left. (From: Herrick, "Introduction to Neurology.")

the *commissural nucleus* which joins together the lower ends of the two solitary tract nuclei.

Of the *secondary neurons* which have their cell stations in the nucleus of the solitary tract but little is known. It seems, however, probable that some of the axons pass to the thalamus, because sensations of taste arouse consciousness. Others would appear to enter the reticular formation of the medulla and there establish synaptic contact with effector

nuclei or cells, particularly with the effector nuclei of the vago-glosso-pharyngeal nerve, and so form a series of visceral reflex neuronie arcs, whilst yet others descend to the spinal cord and so take part in reflex arcs concerned with respiration, coughing, vomiting, and so on. The first of these possible connections, that between the nucleus of the solitary tract and the thalamus, seems to be definitely established.

The Somatic Effector Column. From cells of the somatic effector column are derived the axons which supply the extrinsic muscles of the eye, and the musculature of the tongue, and form the oculo-motor, trochlear, abducent, and hypoglossal nerves. The cells of these neurons are homologous with those of the ventral grey column of the spinal cord, and are, as a matter of fact, a continuation of that column of cells. Like the spinal cord cells they are large, multipolar, and contain well developed Nissl bodies, and they lie in linear series in the grey matter of the brain stem close to the median plane.

The *oculo-motor nucleus* lies in the central grey matter of the cerebral aqueduct opposite the superior colliculus of the midbrain. The axons of these cells pass ventrally through the midbrain in curved bundles, which traverse the medial longitudinal tract, the tegmentum of the midbrain, the red nucleus, and the medial end of the substantia nigra, to emerge at the oculo-motor sulcus as the oculo-motor nerve.

The oculo-motor nerve of human anatomy is a composite nerve. It innervates five of the *extrinsic* ocular muscles, namely, the elevator of the upper eyelid, the superior, medial, and inferior recti, and the inferior oblique, and two *intrinsic* muscles, the ciliary and sphincter pupillæ. The first five are *somatic* muscles, the last two are *visceral*, consequently the oculo-motor nerve contains somatic effector axons and general visceral effector axons, and this composite character of the nerve is indicated in its nuclei. The ocular muscles are controlled by the cells of the oculo-motor nucleus, and the visceral muscles by the Edinger-Westphal nucleus, though only the former belongs to the group now under consideration, namely,

the somatic effector. Further, the cells of the somatic nucleus are not uniformly distributed throughout the nucleus, but are collected into groups of subsidiary nuclei, which are definitely related to the muscles to be supplied.

The oculo-motor nucleus is divided into a lateral paired, and a single, median, unpaired portion. The former is spread out upon the surface of the medial longitudinal tract, and is subdivided into ventral and dorsal portions; the latter is found in the middle line at the upper end and its axons enter the oculo-motor nerves of both sides. There is reason for believing that these several parts of the oculo-motor nucleus are definitely associated with the several muscles to be supplied, though the evidence as to the detail is somewhat conflicting. Bernheimer's experiments would seem to show that the order from above downwards is levator palpebræ superioris, superior rectus, medial rectus, inferior oblique, and inferior rectus.

It should be remembered that the oculo-motor nerve and its nuclei are effector in function, and consequently receptor and other neurons from other sources must be in synaptic contact with the oculo-motor nuclei. The exact source of the receptor impulses which activate the effector oculo-motor nuclei is not, in all cases, definitely known, but certainly includes visual, equilibratory and proprioceptive generally.

The Edinger-Westphal nucleus is, as stated, a visceral effector nucleus and will be discussed with that column.

The *trochlear nucleus* is the next in series. It is situated in the central grey matter of the cerebral aqueduct on the ventral side and opposite the inferior colliculus. It lies close to the lower extremity of the oculo-motor nucleus and close to the median plane and its fellow of the opposite side, and is equally closely connected with the medial longitudinal tract. From this nucleus the axons pass laterally and dorsally around the central grey matter of the cerebral aqueduct, between it and the descending mesencephalic root of the trigeminal nerve. Turning dorsomedially towards the inferior colliculus, the axons enter the upper end of the anterior medullary velum, and there form, with the nerve of the opposite side, the

decussation of the trochlear nerves. Having crossed the median plane the nerve emerges at the medial border of the superior cerebellar peduncle and is eventually distributed to the superior oblique muscle. This nerve is remarkable, inasmuch as it is the smallest of the cerebral nerves, is the only one which emerges from the dorsal side of the neuraxis, and is the only one which undergoes a complete external decussation.

The *abducent nucleus* lies in the dorsal part of the pons opposite the facial colliculus in the floor of the fourth ventricle, and close to the middle line. The nucleus is a small spherical one and, with the genu of the facial nerve, forms the facial colliculus, which, as has been seen, lies just above the medullary striæ and in line with the other somatic effector nuclei. From the cells of the abducent nucleus the axons pass through the whole thickness of the pons to the superficial exit of the nerve, which is at the lower border of the pons near the pyramid of the medulla. In this course the nerve fibres lie on the medial side of the superior olivary nucleus, and on the lateral side of the longitudinal pyramidal fasciculi. The nerve is distributed only to the lateral rectus muscle.

It has already been pointed out that the oculo-motor, trochlear, and abducent nerves are effector in character, and that there must necessarily be receptor sides to the arcs of which they form the effector part. The receptor sides of these ocular muscle arcs are probably derived from many sources. Amongst the more important would appear to be the medial longitudinal tract, and the tecto-spinal tract. In this way provision is made for reflex ocular movements in response to vestibular, visual, and auditory impulses, whilst the trigeminal nerve would also appear to send off collaterals to the ocular nuclei. Lastly, all three are brought under voluntary control by the cortico-bulbar tract from the Rolandic area.

The *hypoglossal nucleus* is a long slender nucleus, about 2cm. in length, which corresponds in position to the hypoglossal nerve triangle in the floor of the fourth ventricle, and extends from the level of the inferior fovea to that of the

decussation of the pyramids. The fibres of the hypoglossal nerve arise as the axons of this nucleus. They pass thence through the entire dorsoventral thickness of the medulla, between its white and grey reticular substance, to emerge upon the surface between the olive and the pyramid. None of its axons are supposed to decussate, though numerous commissural fibres are known to pass between the nuclei of the two sides.

All the somatic effector nuclei supply structures which are under voluntary control, therefore the neurons are here analogous to the "lower motor neurons" of the spinal cord, the "upper motor neurons" being those of the cortico-bulbar tracts. In addition, these somatic effector nuclei are activated reflexly by other impulses, therefore there must be receptor or other neurons establishing synaptic contact with them. In the case of the hypoglossal nerve nucleus such connections would appear to be established by the trigeminal and other cerebral nerves, including the nerve of taste.

The General Visceral Effector Column. The neurons of this group are the equivalents of the pre-ganglionics of the autonomic nervous system in the spinal cord. They supply cardiac and non-striated muscle and glandular tissue, and reach their destinations by making use of the pathways provided for them by the oculo-motor, facial, glossopharyngeal, vagus, and internal branch of the accessory nerves. The nerve cells are of the autonomic effector type, that is, they are small with poorly developed Nissl bodies, and the axons are finely myelinated. In the midbrain and medulla the cells of the group are probably scattered throughout the reticular formation, but in certain places they are definitely collected together into nuclei, which are, from above downwards, the Edinger-Westphal nucleus, the salivary nucleus, and the dorsal nucleus of the vagus.

The *Edinger-Westphal nucleus* is situated in the midbrain immediately above the oculo-motor nucleus. Its axons run out with the oculo-motor nerve and reach the ciliary ganglion, where they establish synaptic contact with the post-ganglionic

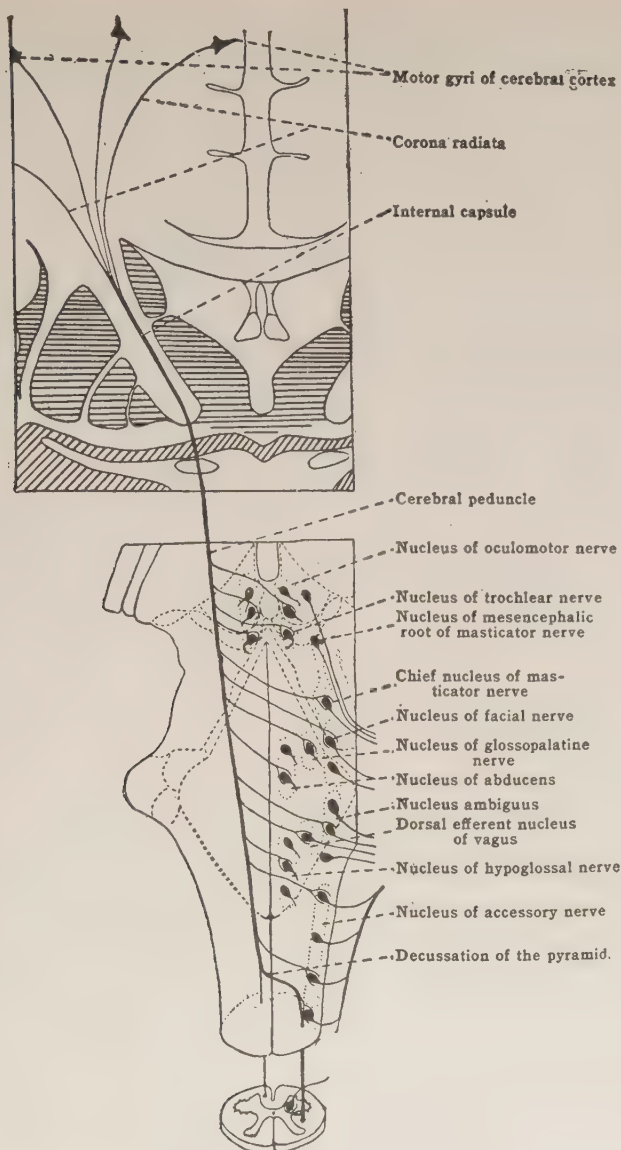


FIG. 66.—Scheme to illustrate the principal or crossed relations of the descending cortical (pyramidal) fibres to the nuclei of origin of the cranial nerves. (From: Morris, "Human Anatomy.")

neurons as described on page 87. It is thus clear that the Edinger-Westphal neurons form the midbrain or tectal autonomies.

The *salivary nucleus* lies in the reticular formation, at the junction of the pons and medulla, some little distance from the floor of the fourth ventricle. The *upper* part of the nucleus lies dorsal to the facial nucleus. Its axons enter the facial nerve, thence through the chorda tympani to the submaxillary ganglion where they establish synaptic contact with the post-ganglionic neurons which proceed to Langley's ganglion and the submaxillary and sublingual salivary glands. From the *lower* part of the salivary nucleus pre-ganglionic neurons pass, *via* the glosso-pharyngeal nerve to the otic ganglion where post-ganglionic neurons continue the path to the parotid gland.

The *dorsal* or *splanchnic nucleus of the vagus* lies in the floor of the fourth ventricle subjacent to the ala cinerea, and immediately dorsolateral to the hypoglossal nucleus. Its axons leave the medulla through the vagus and accessory nerves, but as the latter enter the vagus through the internal branch of the accessory nerve, the ultimate distribution is entirely vagal. The neurons from this nucleus form part of the bulbar autonomies of the parasympathetic system (see page 86) and appear to be distributed to the involuntary muscle of the heart, respiratory passages, œsophagus, stomach, and small intestine, as well as to the pancreas, liver, and other glands.

The neurons of the three nuclei just described form the cranial outflow of the parasympathetic system and belong to the pre-ganglionic effectors. The principles of the neuronics demand that receptor neurons shall establish synaptic contact with the effector neurons. In the case of the vagus nerve, these receptors would appear to traverse the vagus itself, to terminate in the nucleus of the solitary tract, whence a secondary series of receptor neurons link on to the dorsal nucleus, thus completing the neuronics arc. Similar secondary receptor neurons may also pass from the recipient

nuclei of the trigeminal and glossopharyngeal nerves to the dorsal effector vagal nucleus.

The path of receptor neurons to the Edinger-Westphal and salivary nuclei is not sufficiently clear.

The Special Visceral Effector Column. Ranson includes under this term, all those nuclei which preside over the innervation of the striated muscle of the branchial arches, "as distinguished from the general musculature that develops from the myotomes." Other authorities regard these branchial arch muscles as being somatic, and thus term the effector nuclei concerned, namely, the motor nuclei of the trigeminal nerve (first branchial arch musculature), the facial nerve (second branchial arch musculature) and the nucleus ambiguus (third and fourth branchial arch musculature) the *lateral somatic* effector nuclei. On evolutionary and developmental grounds Ranson's terminology is correct, as the branchiæ or gills originally function as viscera. On histological grounds the term "somatic" is almost equally correct, as the effector cells are of the typical somatic effector type. As long as it is understood what nerves and muscles are concerned the distinction between "visceral" and "somatic" is here unimportant.

The effector nuclei concerned are, as just stated, the motor nuclei of the trigeminal and facial nerves, and the nucleus ambiguus of the vago-glosso-pharyngeal nerves, and the muscles are the muscles of mastication, the muscles of expression, and the muscles of the pharynx and larynx.

The effector nuclei of the nerves concerned—trigeminal, facial, glosso-pharyngeal, and vagus—form a broken column of grey matter, which lies in the ventrolateral part of the reticular formation of the pons and medulla some little distance from the floor of the fourth ventricle. As all the muscles to be supplied are voluntary muscles, it is clear that the neurons which have their cell stations in the nuclei under consideration, are the cerebral equivalents of the "lower motor neuron" of the spinal cord, those of the cortico-bulbar tract forming the "upper motor neurons" in the chain. Further, the muscles may react involuntarily to receptor stimuli, therefore, such

receptor neurons must establish synaptic contact with the effector nuclei, and thus complete a neuronie reflex arc.

The *motor nucleus of the trigeminal nerve* lies, as a whole, on the medial side of the main sensory nucleus, and is often described as consisting of two parts—a lower or chief nucleus, and an upper. The *former* is situated within the pons close to its dorsal surface and along the line of the lateral border of the floor of the fourth ventricle. The *upper* portion of the nucleus consists of nerve cells lying along the whole length of the lateral portion of the grey matter of the cerebral aqueduct. The axons from these cells descend as the *mesencephalic root* through the mesencephalon into the pons, and are joined in their descent by the axons from the lower or chief nucleus, and the two together form the *portio minor* or “motor” root of the trigeminal nerve which runs with its mandibular division to the muscles of mastication.

Cortico-bulbar axons terminate around the cells of this nucleus and thus its neurons are brought under the control of the cerebral motor cortex, whilst receptors, chiefly collaterals, are given off to it by the trigeminal and other receptor cerebral nerves, and thus the reflex arcs are established.

The *motor nucleus of the facial nerve* lies in the ventrolateral part of the reticular formation of the pons in line with the nucleus ambiguus of the vago-glosso-pharyngeal nerve, and between the superior olivary nucleus and the nucleus of the spinal tract of the trigeminal nerve. From this nucleus the axons pursue a devious path through the pons, and hence the intra-pontine root of the facial nerve is divided into three parts, termed respectively, the first part, the genu or knee, and the second part.

The *first part* of the facial nerve issues from the dorso-medial side of the nucleus, and passes thence dorsomedially towards the rhomboid fossa of the fourth ventricle, which it reaches on the medial side of the nucleus of the abducent nerve. On the medial or inner side of this nucleus the facial nerve axons then turn upwards for a few millimetres and thus produce that elevation in the floor of the fourth ventricle,

known as the *facial colliculus*. Around the upper end of the abducent nucleus the facial nerve axons describe an acute bend or curve, termed the *genu internum*, whence the *second part* of the root of the facial nerve pursues a ventrolateral course through the pons, between its own nucleus and the spinal tract of the trigeminal nerve to the superficial origin of the nerve from the lateral part of the lower border of the pons.

Like all the other effector nuclei in this series, the facial nerve nucleus is brought under cerebral control by cortico-bulbar neurons from the Rolandic motor area, and thus the facial muscles of expression are under the control of the will. But the facial nerve nucleus also receives receptor and other neurons from many other sources which act as short circuits to the muscles of expression and thus place these muscles under other influences besides those of the will, in which voluntary control is cut out, thus the expression may alter in response to visceral pain, terrifying sights and sounds, and the like. Amongst the neuronie reflex connections definitely established with the

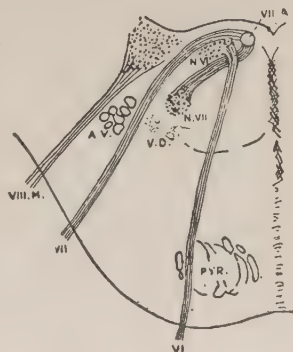


FIG. 67.—(Left.) Plan of origins of 6th and motor root of 7th cerebral nerves. (Thane, adapted from Schwalbe.) The outline represents a transverse section of the lower part of the pons, on to which the course of the facial nerve is projected; VI, 6th nerve; N.VI, its nucleus; VII, facial nerve; VII.A, ascending portion of its root, supposed to be seen in optical section; N.VII, its nucleus; so, superior olive; AV, sensory or bulbo-spinal root of 5th nerve; VIII.M, mesial root of acoustic nerve. (From: Luciani, "Human Physiology.")

facial nerve nucleus are collaterals from secondary receptor neurons in the pons and medulla, from the cochlear nerve of hearing, from the nucleus of the spinal tract of the trigeminal nerve, and from some of the ascending tracts of the spinal cord.

The *nucleus ambiguus of the vago-glosso-pharyngeal nerve* is a long slender column of nerve cells which lies in the grey reticular substance of the medulla, about midway between the inferior olivary nucleus and the emerging rootlets of the vago-glosso-pharyngeal nerve itself. It thus lies more deeply

than the dorsal or splanchnic nucleus, and extends from the place of entrance of the cochlear nerve to the level of the decussation of the fillet. From the large multipolar cells of the nucleus the axons pass first dorsally towards the floor of the fourth ventricle and then turn abruptly laterally to emerge in the glosso-pharyngeal and vagus nerves of the same side, whilst a few decussate to emerge in the nerves of the opposite side. They are distributed to the muscles of the pharynx and larynx.

The nucleus ambiguus and its muscles are placed under voluntary control by cortico-bulbar neurons from the cerebral cortex, but just as with the facial nucleus, numerous other synaptic contacts are effected in the ambiguus nucleus by receptor and other neurons. Amongst these are axons derived from the central tracts of the trigeminal, glosso-pharyngeal and vagus nerves, from receptor tracts of the spinal cord, and from other neurons of the reticular formation.

The Nuclei of the Cerebral Nerves. From the foregoing description of the minute construction of the cerebral nerves, based largely on the researches of American investigators and on the neurological principles enunciated herein of the neuronic arc, it is clear that the older anatomical descriptions and nomenclature are out of date. The terms "recipient nuclei of termination or sensory nuclei" and "effector nuclei of origin or motor nuclei" as applied to the cerebral nerves are misleading, because the so-called "nuclei of termination" are not terminal at all. They are no more terminal than are the gracile and cuneate nuclei for the gracile and cuneate tracts of the spinal cord. They are, like those nuclei, relay or shunting stations for the nerve impulses transmitted over the receptor cerebral nerves. Similarly with the so-called "nuclei of origin." These are no more the origin of the effector cerebral nerves than are the ventral spinal grey cells of the spinal nerves, but they are exactly like those cells, the place of origin of the "lower motor neuron," the "upper motor neuron" being, in the cases of the cerebral nerves, the cortico-bulbar neurons from the Rolandic area, and in the cases of the spinal nerves,

the cortico-spinal tracts. Further, the nuclei of the cerebral nerves, afford, as has been pointed out, numerous facilities for branching nerve impulse, and for the admission into the arc of nerve impulses from many other sources, as, for example, the facial nerve nucleus described above. Lastly, the classification of the cerebral nerves into twelve pairs, though well established by usage, is quite obsolete and requires revision, and it would probably be a step in the right direction were the numbers now attached to those nerves to be altogether discarded.

The Cerebral Nerves. Taking the current anatomical names without the numerals as the basis, the cerebral nerves may be briefly summarised as follows:

The *terminal nerve* "is a recently discovered nerve which arises from the cerebral hemisphere in the region of the medial olfactory tract or stria. It is closely associated with the olfactory nerve and its fibres run to the nasal septum." (Ranson.) The functional significance of this nerve is, as yet, unknown. Possibly it may prove to be of the corticifugal type of neuron associated with the sense of smell, in much the same way as it is believed that similar corticifugal neurons are associated with the other pathways of special sense. Arey has, for example, demonstrated effector fibres in the optic nerves of fishes which control the movement of the retinal elements in response to light.

The *olfactory nerves* are composed of bipolar receptor neurons the cell stations of which are in the nasal mucous membrane. The non-medullated central processes of these cells constitute the olfactory nerves and establish synaptic contact with the secondary olfactory neurons in the olfactory bulb. Consequent on the profound evolutionary changes which have taken place in the sense of smell, its alteration from an entero-ceptive to an extero-ceptive sense, and its comparative atrophy, as an extero-ceptive special sense of man, it is not, in the human being of great importance, though it is certainly associated with consciousness.

The so-called *optic nerve* is not a nerve at all, but is an

essential part of the brain, whose function is the central transmission of the extero-ceptive sense of sight. It is composed of somatic extero-ceptive neurons whose primary cell stations are in the retina. (See page 316.)

The *oculo-motor*, *trochlear*, and *abducent nerves* form a group of somatic effectors for the control of the muscles of the eyeball. The oculo-motor is, however, complicated by the fact that it also contains the midbrain or tectal autonomies of the parasympathetic system, and thus the nerve is both somatic and visceral.

The *portio major of the trigeminal nerve* is a receptor somatic nerve for both extero-ceptive impulses from the skin and proprio-ceptive impulses from the muscles of mastication.

The *portio minor of the trigeminal nerve* is a visceral (or somatic) effector nerve for the muscles of mastication derived from the first branchial arch. It is possible that the proprio-ceptive impulses just referred to as being transmitted centrally from the muscles of mastication by the portio major may really be transmitted through the portio minor, because, according to Johnston, the mesencephalic root of the trigeminal is receptor in function, not effector as previously described.

The *facial nerve* is an effector visceral (or somatic) nerve for the muscles of expression derived from the second or hyoid branchial arch.

The *intermediate nerve* is a visceral receptor and effector nerve which makes use of the facial nerve and its branches to establish its connections. As regards its visceral *receptor* neurons these have their cell stations in the geniculate ganglion in contact with the facial nerve. The peripheral processes reach the taste buds on the ventral two-thirds of the tongue by way of the facial nerve trunk, chorda tympani and lingual nerves, whilst the central branches pass through the intermediate nerve to the solitary tract and establish synaptic contact with the neurons of the nucleus of that tract.

The *effector* neurons of the intermediate nerve form part of the pre-ganglionic neurons of the bulbar autonomies of the

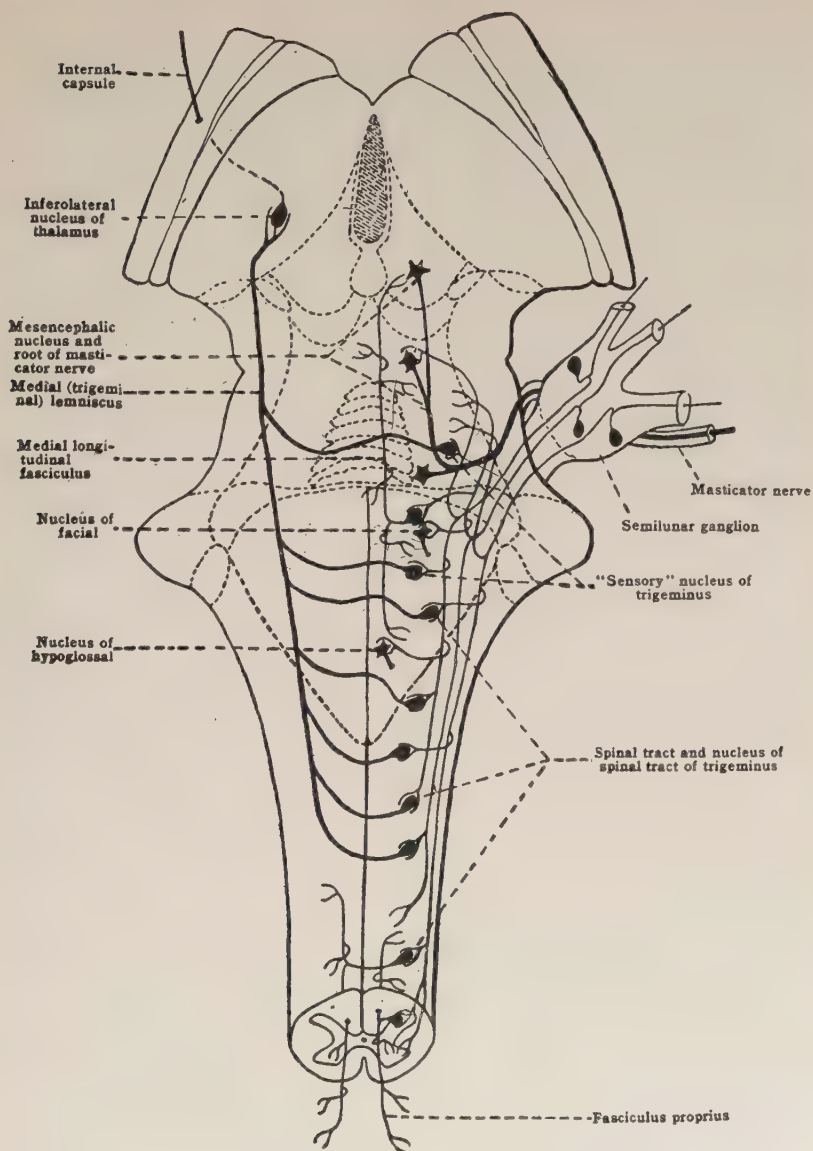


FIG. 68.—Diagram illustrating the principal cortical connections of the trigeminal and masticator nerves, exclusive of their relations to descending cerebral or pyramidal fibres. (From: Morris, "Human Anatomy.")

parasympathetic system and are, therefore, visceral. The cell stations are in the upper salivary nucleus, and the axons run thence by way of the intermediate nerve, facial nerve trunk, chorda tympani, and lingual nerve to the submaxillary ganglion, where they terminate by establishing synaptic contact with the post-ganglionic neurons which convey the impulses to Langley's ganglion and the submaxillary and sublingual glands.

The *cochlear nerve of hearing* is a somatic extero-ceptive nerve, and has been fully described on page 205.

The *vestibular nerve of equilibration* is a somatic proprioceptive nerve. (See page 207.)

The *glossopharyngeal nerve* is a mixed receptor and effector visceral nerve. As already pointed out, if the branchial musculature be regarded as somatic, then the nerve is both visceral and somatic. *Receptor neurons*, with their cell stations in the ganglion petrosum, send their peripheral processes to the taste buds of the posterior or dorsal third of the tongue, and their central processes to the solitary tract and its nucleus. These neurons subserve, therefore, the special visceral function of taste. Other neurons of similar origin and course, except as regards their peripheral processes, which ramify about the mucous membrane of the pharynx and dorsal third of the tongue, convey visceral receptor impulses from these parts. The *general visceral effector neurons of the glossopharyngeal nerve* form part of the pre-ganglionic neurons of the bulbar autonomies of the parasympathetic system. Their cell stations are in the inferior salivary nucleus and their axons run to the otic ganglion where they establish synaptic contact with the post-ganglionic effectors which convey the impulses to the parotid gland.

From the *nucleus ambiguus* effector axons pass through the glossopharyngeal nerve to the stylopharyngeus muscle, one of the muscles derived from the third branchial arch.

The *vagus nerve* is a mixed somatic and visceral nerve and contains both receptor and effector axons. Through this nerve pass a large proportion of those visceral branches which col-

lectively form part of the bulbar autonomies of the parasympathetic system. *Somatic receptor neurons* have their cell stations in the jugular ganglion, their peripheral branches run through the auricular nerve to the skin of the ear, from which they convey extero-ceptive impulses. The central processes pass to the spinal tract nucleus of the trigeminal nerve, so that it is quite possible that this is another instance of the neurons of one nerve (trigeminal) utilising another (vagus) as a pathway. *Visceral receptor neurons*, forming part of the bulbar portion of the parasympathetic system have their cell stations in the ganglion nodosum. The peripheral axons extend through the vagus to the pharynx, larynx, trachea, œsophagus, and the thoracic and abdominal viscera. The central processes course to the solitary tract nucleus through the solitary tract. The *visceral effectors* of the vagus form another portion of the bulbar outflow of the parasympathetic system. The cell station for the vagal pre-ganglionic neurons of this system is the dorsal motor nucleus of the vagus, whence the axons run through the vagus to establish synaptic contact with the post-ganglionic neurons of the system and thus innervate the thoracic and abdominal viscera. From the *nucleus ambiguus* effector axons proceed through the vagus to the striated musculature of the pharynx and larynx, that is, to the musculature of the third and fourth branchial arches and hence these neurons belong to the special visceral (or somatic) group.

The *accessory nerve* is not, even in part, an independent cerebral nerve. Its anatomical bulbar root is part of the bulbar outflow of the parasympathetic system, and these neurons have their cell station in the dorsal motor nucleus of the vagus, but their axons reach the vagus by a circuitous route, namely, through the bulbar rootlets of the accessory nerve, thence through its internal branch, and so back into the vagus, through which they are distributed, as part of the vagal parasympathetic system. Other effector fibres from the *nucleus ambiguus* reach the vagus in a precisely similar manner. The bulbar portion of the anatomical accessory nerve and its inter-

nal branch are thus seen not to be an independent nerve, but only an outlying part of the vagus nerve, and like that nerve belong chiefly to the autonomic nervous system, and only to a lesser extent to the somatic.

The *cervical root* of the anatomical accessory is thrown into the external branch of the nerve, and is thus not a cerebral nerve, but a spinal, having its effector cells in the ventral grey column of the upper five or six cervical segments of the spinal cord. It supplies the sterno-cleido-mastoid and trapezius muscles.

The *hypoglossal nerve* is a purely somatic effector nerve, distributed only to the muscles of the tongue. The fact that the hypoglossal appears, anatomically, to supply other muscles, is simply due to another instance of certain nerve fibres (cervical) utilising another nerve trunk (hypoglossal) to reach their destination.

Summary. The complexities of the structure of the cerebral nerves are more apparent than real, and are probably due, first, to the retention of an old and obsolete system of numbering and nomenclature, which has not kept pace with recent discovery; second, to a failure to realise that both somatic and autonomic nerve systems are component elements of some of the cerebral nerves; third, to an inability, sometimes, but not always, due to conflicting or insufficient evidence, to realise the direction in which the cerebral nerve neurons are conducting, that is, whether they are receptor or effector in function, and lastly, to an erroneous mental picture generated by the terms "nuclei of origin and of termination" which, as applied to the cerebral nerve impulses, give no indication of the true function of the nerves.

The real difficulties in the cerebral nerves are, first, that the course pursued by their axons have, in some instances, not been definitely determined and can only, at the moment, be conjectural; second, that cerebral nerve neurons so frequently make use of another nerve trunk to reach their destinations, and these anatomical pathways are not always definitely known, as for example, the central course of the

receptors for taste, where there are, at least, two conflicting schools of thought. Lastly, experimental sections of certain cerebral nerve trunks, such as the vagus, where neurons are coursing in both directions, that is, receptor and effector, may furnish erroneous conclusions.

CHAPTER XX

THE CEREBELLUM

The Cerebellum. The cerebellum is the head ganglion of the proprio-ceptive mechanism. Any interference with the receptor impulses normally transmitted to the cerebellum, whether induced experimentally, or by disease, prevents the normal functioning of that organ, and produces characteristic phenomena. Destruction of the dorsal white columns of the spinal cord, for example, as in locomotor ataxia, leads to muscular inco-ordination, because the cerebellum now receives little or no information as to the tension and length of the muscles, and so is unable to regulate them. Under these conditions the cerebrum may be called upon to undertake such muscular regulation through visual impulses. Again destruction of the vestibules of the internal ear will interfere with cerebellar functions until re-education can occur through the cerebral cortex and its numerous connections with the cerebellum.

Naked Eye Anatomy of the Cerebellum. The cerebellum, or small brain, lies within the posterior fossa of the cranium dorsal to the pons and medulla, and is separated from the cerebrum by the tentorium cerebelli.

It has long been customary to divide the cerebellum into three parts, a central unpaired portion, the *vermis*, so-called because it is supposed to resemble a worm bent upon itself to form a complete circle, and two large, lateral portions, the *cerebellar hemispheres*, which are connected together by the vermis. These three several parts are further described as possessing superior and inferior surfaces.

On the ventral side the two hemispheres of the cerebellum are separated by a shallow, large and wide notch, the *anterior*

cerebellar notch. This is bounded laterally by the two hemispheres, and in the median plane by the vermis. In the recent condition there project into it the inferior colliculi of the mid-brain and the superior cerebellar peduncles.

On the dorsal side there is a second notch, small and narrow,

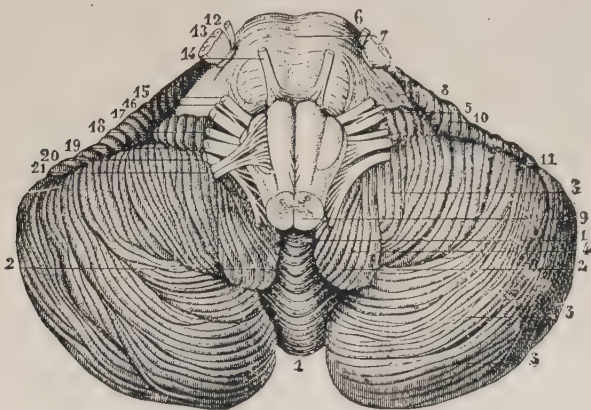


FIG. 69A.—Inferior surface of cerebellum with pons Varolii and medulla oblongata. (Sappey, after Hirschfeld and Leveillé.) 1, 1, inferior vermiform process; 2, 2, median depression or vallecule; 3, 3, postero-inferior lobe of hemisphere; 4, amygdala; 5, flocculus; 6, biventral lobe; 7, pons Varolii; 8, middle peduncle of cerebellum; 9, medulla oblongata; 10, 11, anterior part of great horizontal fissure; 12, 13, smaller and larger roots of fifth pair of nerves; 14, sixth pair; 15, facial nerve; 16, pars intermedia; 17, auditory nerve; 18, glossopharyngeal; 19, pneumogastric; 20, spinal accessory; 21, hypoglossal nerve. (From: Luciani, "Human Physiology.")

and termed the *posterior cerebellar notch*. It is occupied by the falx cerebelli.

On the inferior surface of the cerebellum, between its two hemispheres and in the median plane, is a deep ventrodorsal depression, termed the *vallecule cerebelli*, formed by the nodule, uvula, and pyramid of the vermis, and occupied by the medulla.

On both surfaces of the hemispheres and vermis there are visible numerous narrow grooves, the *sulci cerebelli*, which run approximately parallel to the dorsal border of the cere-

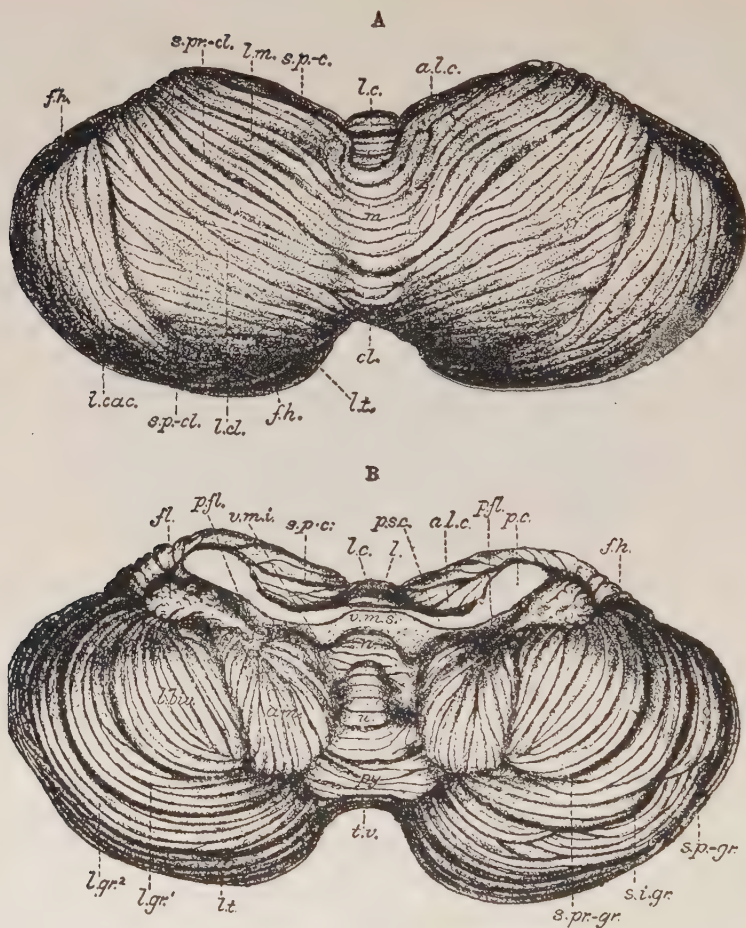


FIG. 69B.—Views of upper (A) and lower (B) surfaces of human cerebellum. Natural size. From photographs. (Schäfer.) In A: *l.c.*, lobulus centralis; *a.l.c.*, ala lobuli centralis; *m.*, culmen monticuli; *l.m.*, lobus culminis; *cl.*, clivus; *l.cl.*, lobus clivi; *l.cac.*, lobus cacuminis; *l.t.*, lobus tuberis; *s.p.-c.*, sulcus post-centralis; *s.pr.cl.*, sulcus pre-clivalis; *s.p.-cl.*, sulcus post-clivalis; *f.h.*, fissura horizontalis magna. In B: *l.*, lingula; *l.c.*, lobus centralis; *a.l.c.*, ala lobuli centralis; *s.p.-c.*, sulcus post-centralis; *v.m.s.*, velum medullare superius; *p.s.c.*, pedunculus cerebelli superior; *p.c.*, pedunculi cerebelli medius et inferior; *n.*, nodulus; *v.m.i.*, velum medullare inferius; *p.fl.*, pedunculus flocculi; *fl.*, flocculus; *u.*, uvula; *am.*, amygdala; *py.*, pyramis; *l.biv.*, lobus biventralis; *t.v.*, tuber valvulae seu posticum; *l.t.*, lobus postero-inferior; *l.gr.¹*, lobulus gracilis anterior; *l.gr.²*, lobulus gracilis posterior; *s.pr.-gr.*, sulcus pre-gracilis; *s.i.-gr.*, sulcus intra-gracilis; *s.p.-gr.*, sulcus post-gracilis; *f.h.*, fissura horizontalis magna. The vallecule has been somewhat opened out to display the parts of the lower worm. (From: Luciani, "Human Physiology.")

bellum and break up the surface into narrow strips of cortical substance, termed *gyri cerebelli*. Of the various sulci one of the deepest and best marked courses round the periphery of the cerebellum, and is termed the *horizontal sulcus*. It serves to divide each hemisphere of the cerebellum into its superior and inferior surfaces.

By the older Anatomists both the cerebellar hemispheres and the vermis were quite arbitrarily divided up into lesser

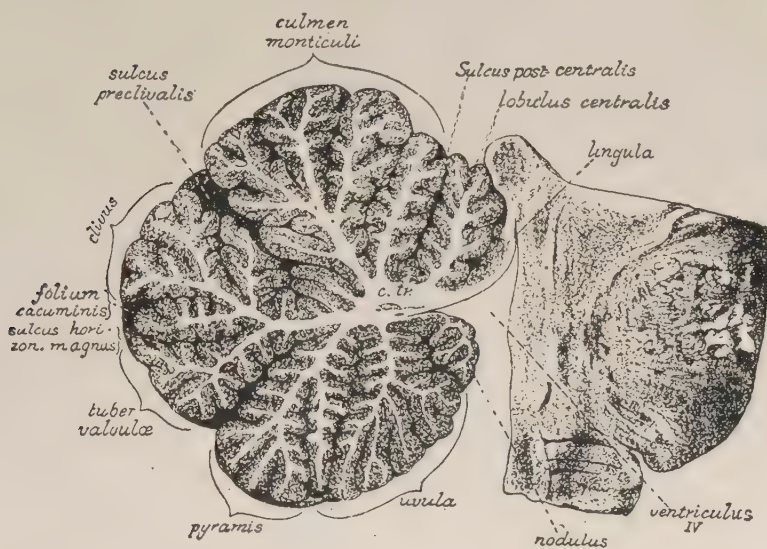


FIG. 70.—Median section of vermis. (Luciani, "Human Physiology.")

areas termed lobules, but as these are now known to have no morphological or functional significance, it is quite unnecessary to perpetuate the memory of a useless piece of information.

Morphological Subdivision of the Cerebellum. Recent research by Elliot Smith, Bolk, Ingvar, and others, has shown that the *fissura prima* is an important and constant cerebellar fissure in all mammals. This fissure is found on the superior surface of the cerebellum, and runs right across both cerebellar hemispheres and vermis, about midway between the anterior and posterior cerebellar notches. All that portion of the cere-

bellar hemispheres and vermis which lies in front of the fissura prima, between it and the brain stem, is the *anterior lobe of the cerebellum*, and is its morphologically oldest part. As thus defined the anterior cerebellar lobe comprises those parts of the superior vermis termed by the older Anatomists, the lingula, central lobule, and the culmen monticulus, as well as that portion of each cerebellar hemisphere, previously known as the anterior part of the quadrangular lobule. This

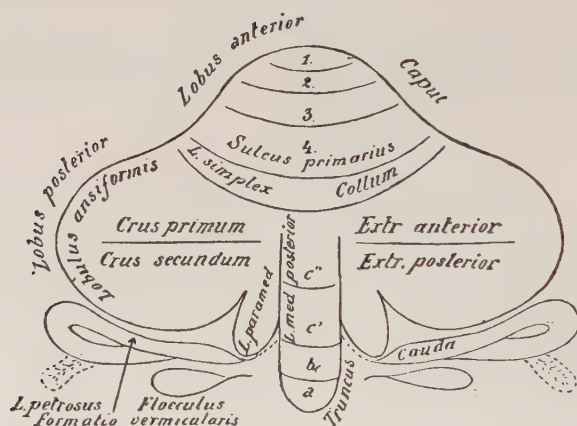


FIG. 71.—Diagram of lobules of mammalian cerebellum. (After Bolk, simplified by van Rynberk.) Left side of figure gives Bolk's new terms for the lobules; right side, the probable localisation, according to Bolk, of the relation in different mammals between lobular development and the functional development of different groups of muscles. (From: Luciani, "Human Physiology.")

anterior lobe of the cerebellum is shaped somewhat like a butterfly, and morphologically, is a median unpaired structure.

The *middle lobe of the cerebellum* is a more complex formation than the anterior lobe, because it is a later evolutionary addition, and varies in different animals according to the requirements of the animal. According to Ingvar it comprises, when complete, a simple lobule, a median lobule, and two lateral extensions of the latter. The *lobulus simplex*, like the

anterior lobe of the cerebellum, is a median unpaired structure which stretches right across the superior cerebellar hemispheres and vermis, immediately behind, or dorsal to, the fissura prima. It comprises those parts ordinarily designated the posterior part of the quadrangular lobule and the declivus monticulus. The *median lobule* is the tuber vermis of the

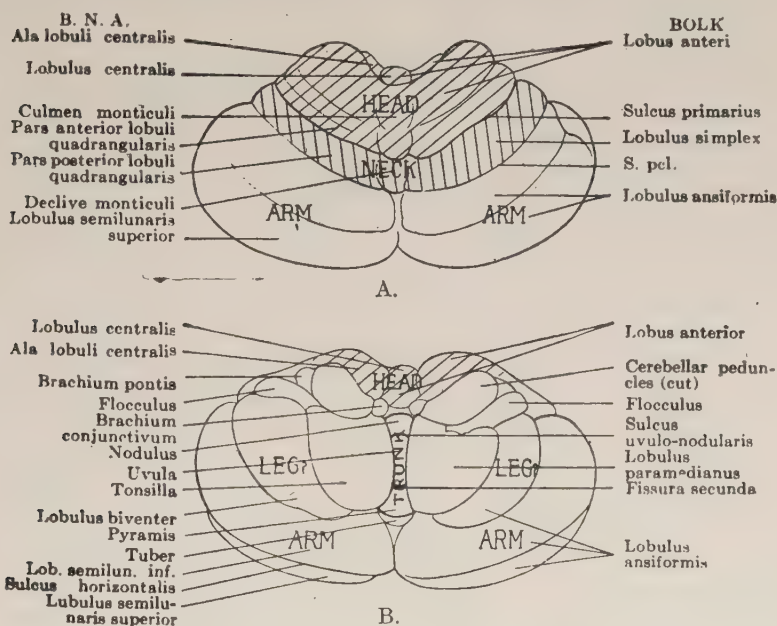


FIG. 72.—The human cerebellum. A. From above; B. From below. (From: Herrick, "Introduction to Neurology.")

older Anatomists, and may be readily recognised in the human cerebellum at the occipital end of the inferior vermis. The *two lateral extensions of the median lobule* consist of two parts, the ansiform lobule and the paramedian lobule. The *ansiform lobule*, relatively small in most mammals, and very large in man, comprises the greater dorso-lateral portion of both cerebellar hemispheres, on both surfaces. It thus corresponds to the superior and inferior semilunar lobules and the biventral lobule. The *paramedian lobule* is the tonsil of

the older descriptions, and in man has become displaced on to the inferior vermis by the great growth of the ansiform lobule.

The *posterior lobe of the cerebellum*, like the middle lobe, is also composed of median and lateral parts. The *median part*, also termed the posterior median lobule, comprises the nodule, uvula, and pyramid, that is, all the inferior vermis except the tuber. The *lateral parts* of the posterior lobe of the cerebellum comprise, on each side, the flocculus and the paraflocculus. In man the flocculus lies upon the inferior surface of the cerebellum, and the paraflocculus is in a rudimentary condition.

Functional Localisation in the Cerebellum. The morphological subdivision of the cerebellum, which has just been given, is not of academic importance only; it has a functional significance. "By comparison of the size of these subdivisions with the degree of development and functional importance of the various groups of muscles in different animals Bolk endeavoured to show that each of these parts was related to a particular group of muscles." (Ranson.) The *anterior lobe of the cerebellum* appears to be functionally concerned with the movements of the head. The *lobulus simplex* of the middle lobe of the cerebellum is a similar unpaired centre for movements of the neck, whilst the area for the control of bilateral movements of the trunk is limited to the inferior vermis, the tuber vermis excluded, which apparently controls those movements of the extremities which are strictly bilateral in character. The greater portions of the cerebellar hemispheres are thus set free, in man, for the control of muscles of the limbs. Whilst Bolk's general conclusions have received both experimental and clinical confirmation, they are probably not quite accurate in every detail. Ingvar, for example, thinks that the anterior and posterior lobes of the cerebellum are probably concerned with the maintenance of the equilibrium of the body as a whole, whilst the middle lobe contains centres for the control of the musculature of the neck and extremities, as outlined by Bolk. That particular portion of the middle

lobe of the cerebellum termed the median lobule or tuber vermis, is for the control of bilateral co-ordinated movements of both members of a pair of limbs, whilst the lateral extensions of this lobe into the cerebellar hemispheres control the separate movements of such limbs.

Naked Eye Connections of the Cerebellum. The cerebellum is connected to the cerebrum, pons and medulla, by three pairs of massive strands, termed respectively, the superior, middle, and inferior cerebellar peduncles.

The *superior cerebellar peduncle* or the *brachium conjunctivum*, on emerging from the hemisphere of the cerebellum, lies on the immediate medial side of the middle cerebellar peduncle, and passing upwards, lies at first on the dorsal side of the pons and on the lateral side of the fourth ventricle of which it is a lateral boundary. Converging upon its fellow, it, at the same time, sinks into the substance of the pons, and eventually becomes, with the exception of its dorsal edge, entirely submerged therein. In this part of its extent it is connected to its fellow of the opposite side by the anterior medullary velum, on which rests the lingula of the superior vermis. It finally disappears from view by sinking altogether into the substance of the midbrain under cover of the inferior colliculus.

The *middle cerebellar peduncle* or the *brachium pontis* is the largest of the three cerebellar peduncles. It is formed by the fibræ pontis, and enters the cerebellar hemisphere on the lateral sides of the superior and inferior cerebellar peduncles. It forms an important link in the cerebro-ponto-cerebellar pathway.

The *inferior cerebellar peduncle* or the *restiform body*, after emerging from the medulla, passes craniolaterally (upwards and outwards) on the dorsal side of the medulla, and then takes part in the formation of the lower lateral boundary of the fourth ventricle. It there turns sharply dorsally, at a right angle to its previous course, to enter the cerebellum between the other two peduncles.

Structure of the Cerebellum. If sections be cut into the

cerebellum, the white substance will be seen to form a solid compact mass in the interior, which is termed the *medullary body*. This sends out stout stems, the *medullary laminæ*, into all the gyri of the cerebellum, from which secondary and tertiary stems arise, thus producing a branched, tree-like appearance, termed in consequence the *arbor vitæ*. Around the central white medullary core is the grey cortical substance which forms a continuous external covering for the cerebellum, and in addition is collected together in the interior of the white substance, in the form of isolated discrete nuclei, which are, in lateromedial order, the dentate, emboliform, and globose nuclei. In the vermis the white substance is reduced to a relatively thin bridge thrown across between the two hemispheres. Within this is another detached nucleus, the roof nucleus (*nucleus fastigii*).

The Cerebellar Grey Nuclei. The cerebellar nuclei comprise the dentate, emboliform, and globose nuclei, which are paired, and the roof nucleus of the vermis.

The *dentate nucleus* consists of a corrugated lamina of grey matter folded upon itself so as to enclose a portion of the central white substance. It thus presents an open mouth, termed the hilus, directed craniomedially, out of which stream the bulk of the axons of the superior cerebellar peduncle. The layer of medullated axons which encapsulates the lateral surface of the dentate nucleus forms the capsule. The general construction of the dentate nucleus thus resembles that of the inferior olivary nucleus of the medulla. The dentate nucleus is well developed only in those animals which possess large cerebellar hemispheres; it receives fibres from the cerebellar cortex and is said to be largely concerned with the co-ordination of movements of the arm and hand of the same side.

The *emboliform nucleus* lies immediately medial to the dentate nucleus, to which it thus bears the same relationship as does the medial accessory olivary nucleus to the inferior olivary nucleus in the medulla. Like the dentate nucleus the

emboliform nucleus is a cell station between the cerebellar cortex and the red nucleus of the midbrain.

The *globose nucleus* lies medial to the emboliform nucleus and receives axons chiefly from the vermis. The axons from

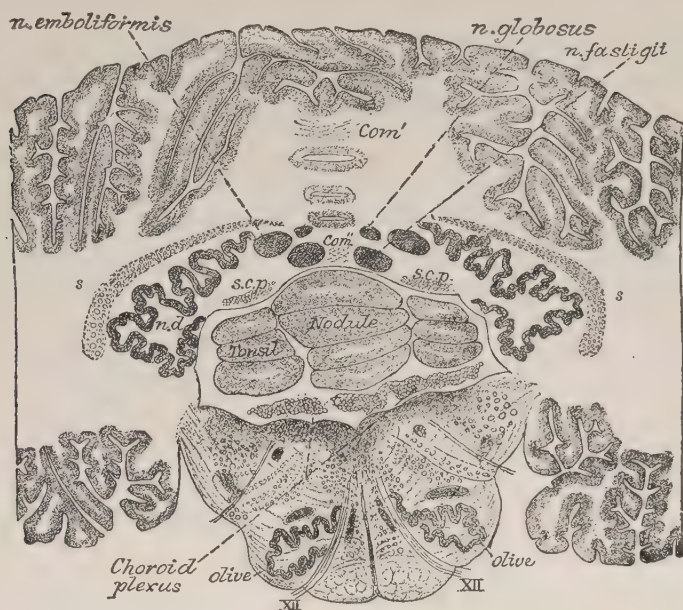


FIG. 73.—Section across the cerebellum and medulla oblongata, showing position of nuclei in white matter of cerebellum. (Stillling.) $\frac{1}{2}$. n.d., nucleus dentatus cerebelli; s, band of fibres derived from restiform body, partly covering dentate nucleus; s.c.p., commencement of superior cerebellar peduncle; com'. com'', commissural fibres crossing in median white matter. (From: Luciani, "Human Physiology.")

all three nuclei appear to pass into the superior cerebellar peduncles.

The *roof nucleus* lies in the central white substance of the vermis, close to the middle line of the body and its fellow of the opposite side. It is connected to its fellow of the opposite side by means of commissural fibres, and to the vestibular nuclei by means of the vestibulo-cerebellar tracts. The roof nucleus would thus appear to be chiefly concerned with bilateral movements, especially those concerned with equilibration,

and, like the globose nucleus, receives axons chiefly from the vermis. Further investigation will probably show that these nuclei have a functional significance similar to that of the cerebellar cortex.

General Structure of the Cerebellum. Before proceeding to the study of the intricacies of minute cerebellar neuronie construction, attention should be directed to some general facts which materially assist the understanding of both the structure and functions of the cerebellum.

The cerebellum is the expanded dorsal portion of the metencephalon, and in all mammals ranks next in size to the cerebral hemispheres. In lower vertebrates the cerebellum is more variable in size, but is otherwise constant in its general characters.

The cerebellum is supra-segmental in position and construction. This differentiation of the central nervous system into segmental and supra-segmental is extremely important. The main several parts of these are as follows:

SEGMENTAL.	SUPRA-SEGMENTAL.
The spinal cord.	The tectum or roof of the mid-brain.
The medulla, pyramids excluded.	The cerebellum.
The dorsal pons.	The interbrain.
The tegmentum of the midbrain.	The cerebrum.

The characteristics of the *segmented* portions of the neuraxis may be thus stated:

1. The general plan of the neuronie construction of the segmented portions of the neuraxis is practically constant in all vertebrates, and is relatively simple, that is, there are comparatively few interposed neurons between the receptor and effector limbs of the neuronie arcs.

2. The segmented neuraxis was originally endowed with, and persistently retains control of, the definitely fixed and fundamental organic reactions, that is, those which are usually reflex, unconscious, and essential to the maintenance and preservation of life.

3. A segmented neuraxis is incapable of much increase in the amount of its grey matter (cell bodies of neurons) because such matter is situated in the interior, is everywhere surrounded by white matter, and is thus incapable of extension.

The *supra-segmental* portions of the neuraxis, on the other hand, are much later evolutionary additions to the neuraxis. They serve the purposes of some special additional functions for which the segmental neuraxis does not provide. As the grey matter is situated on the exterior in all supra-segmental additions, there is ample room for extension of grey matter,

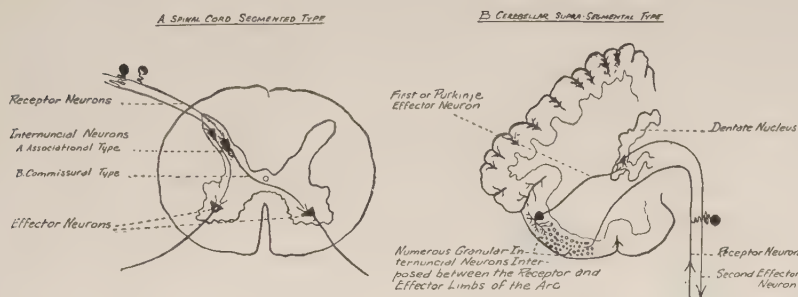


FIG. 74.—Two diagrams to illustrate the different types of junctional or internuncial neurons found in the segmented spinal cord and the suprasegmental cerebellum. See pages 2, 58, 19, 32, 35, 123, 127, 276, 353.

and thus the animal is adapted to much more complex correlations of nerve impulses. In those lower animals with a segmented neuraxis only, the reactions to the environment, or the behaviour, will be fixed, constant, and innate (instinct), whereas in animals with a supra-segmental cerebral cortex (mammals and man) the reactions to the environment or the behaviour will vary (reason).

If these general laws of supra-segmental neuraxal construction be applied to the cerebellum it will be found:

1. That the grey matter is on the exterior of the cerebellum, *not* the interior, as in the segmental spinal cord. Such an arrangement enhances the possibilities of expansion of the

cortex of the cerebellum which contains the cell-bodies, and, therefore, of the numbers of nerve cells.

2. That the numbers of short neurons interposed between the receptor and effector limbs of the cerebellar supra-segmental neuronics are very much more numerous than in the spinal cord segmental neuronics, and that this structural difference must possess a functional significance. It is the presence of these numerous interposed or internuncial neurons in the cerebellum which accounts for the immense amount of potential nerve energy which is stored up in an available form, in the neurons of the cerebellar cortex, and explains the physiological fact that the cerebellum appears to be constantly exerting a stimulating or tonic effect upon the voluntary muscles of the body.

Minute Construction of the Cerebellar Cortex. The surface of the cerebellum is divided, as previously stated, into lobes. Each lobe is subdivided, by shallow sulci, into narrow tracts termed *gyri*. These gyri vary from 2 to 4mm. in width, pursue a curved course within the lobule in which they occur, and, speaking generally, run parallel to one another and to the sulci bounding the gyrus. When the gyri are sectioned at right angles to their course, each one is seen to consist of a central tract of white substance, covered in by the continuous sheet of cortical grey substance.

The cerebellar cortex, usually about 1mm. in thickness, differs, histologically, from the cerebral cortex, in possessing the same structure in all its parts, thus indicating that cerebellar function is everywhere the same. As a result, however, of differing connections, different parts of the cerebellum may act on different muscle groups. Further, the structure of the cerebellum is practically the same in all animals, and consists of three distinct microscopic layers. These are from without inwards:

1. An external grey molecular layer, receptor in function.
2. A middle layer composed of a single row of Purkinje cells, effector in function.
3. An internal yellowish, or reddish brown granular layer, receptor in function.

The Molecular Layer of the Cerebellar Cortex. The molecular layer of the cerebellar cortex, or the outermost layer, is of uniform thickness, and is largely composed of incoming medullated receptor axons, and of short, internuncial neurons of a granular appearance, and known histologically, as basket and cortical cells.

The *basket cells* have a highly specialised form and are chiefly found within the deeper parts of the molecular layer. These cells possess several stout branching *dendrons*, and a very characteristic axon, to which chief interest attaches. This *axon* extends across the gyrus in an approximately horizontal plane along, and external to, the row of effector Purkinje cells. During this course the axon gives off numerous collateral branches to the Purkinje cells, as does also the terminal branch itself. Both the collaterals and the terminals surround the Purkinje cells in a basket-like network, an arrangement which brings each basket cell into the closest relationship with the Purkinje cells, and explains the name applied to the cells. These basket cells are clearly of the internuncial type, interposed, for storage or other purpose, between the receptor and effector neurons of the cerebellum.

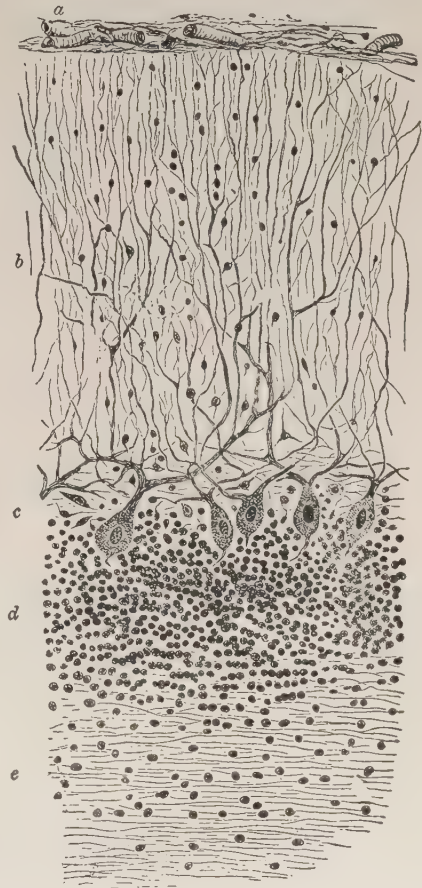


FIG. 75.—Section of cortex of cerebellum. (Sankey.) *a*, pia mater; *b*, external layer; *c*, layer of corpuscles of Purkinje; *d*, inner or granular layer; *e*, white matter. (From: Luciani, "Human Physiology.")

The *cortical* or *stellate cells* are chiefly found in the more superficial strata of the molecular layer, and are of the ordinary Golgi type II variety.

The Middle Layer of the Cerebellar Cortex. The middle layer of the cerebellar cortex is composed of a single row of a very special type of effector cells, known as *Purkinje cells*. These cells are the most distinctive nervous elements of the cerebellum. They are disposed in a single row close to the boundary line between the molecular and granular layers, and are more numerous and more closely packed upon the summit of a gyrus than along a sulcus.

The Purkinje cells have a large flask-like *body*, from the pointed and external end of which arise one or more highly characteristic dendrons. The chief *dendrons*, relatively thick and very short, soon divide into two branches, which at first diverge and run more or less horizontally, and then turn sharply outwards to assume a course perpendicular to the surface, where they undergo repeated subdivision, and thus come to resemble the antlers of a deer. The dendrons ramify within the outermost or molecular layer of the cerebellar cortex, and there establish synaptic contact with the short internuncial basket and cortical cells of that layer. The *axons* of the Purkinje cells arise from the rounded basal, or internal, end of the cell, and at once traverse the deeper granular layer in order to enter the white medullary core of the cerebellum. The axons of the Purkinje cells do not actually leave the cerebellum, but terminate in synaptic contact with the neurons of the deep grey nuclei of the cerebellum, particularly in the dentate nucleus, in which arise other neurons which carry the impulses out of the cerebellum. It is important to note that the Purkinje cells form the sole effector system of the cerebellum.

The Internal Granular Layer of the Cerebellar Cortex. The internal granular layer of the cerebellar cortex, of a rust-brown tint when fresh, and deeply coloured in stained preparations, is thickest on the summit of a gyrus, and thinnest opposite a sulcus. It contains a very large number of the

internuncial type of neurons, of which two varieties may here be recognised, namely, granule cells and Golgi Type II, of which the former largely predominate.

The *granule cells* are so numerous and so closely packed as to confer upon the layer its density. They possess three to six short radiating *dendrons*, which end in peculiar claw-like ramifications which come into synaptic relationship with other granule cells. The *axons*, directed towards the surface, enter the molecular layer, within which, at various levels corre-

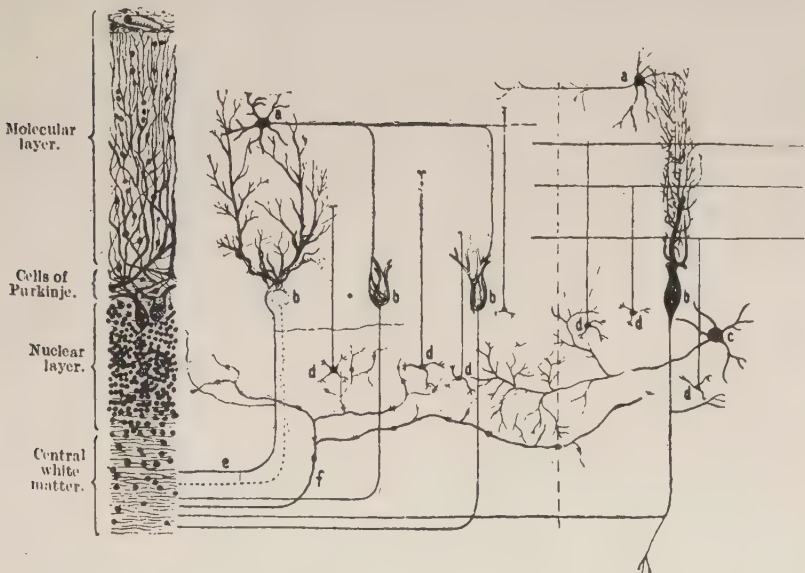


FIG. 76.—Schema of constituent elements of cerebellum. (Modified from Böhm and Davidoff.) On the left is a section of the cortex as it appears when stained by ordinary methods. The middle portion represents diagrammatically a section at right angles to the laminae, while to the right of the dotted line the section is taken in the same plane as the laminae. *a*, Star-shaped cells of molecular layer; *b*, *b'*, cells of Purkinje; *c*, Golgi cell; *d*, small cells of nuclear layer; *e*, tendril fibre; *f*, moss fibre; *g*, axon of cell of Purkinje. (From: Starling, "Principles of Human Physiology.")

sponding to the depth of the cells, they undergo a T-like division. The two resulting branches run parallel to the surface of the gyrus, and therefore at right angles to the dendrons of the cells of Purkinje, with which they probably establish synaptic contact,

The *Golgi Type II*, or *stellate cells*, are present in this layer in varying number, but are never numerous. They lie close to the outer limit of the granular layer, and possess a *cell body* of uncertain and irregular form, from which several richly branched *dendrons* pass in various directions, but chiefly into the molecular layer. The *axon* is most distinctive, as it very soon breaks up into an arborescence of unusual extent and complexity, which, however, is confined to the granular layer.

Medullated Axons in the Cerebellar Cortex. Mingled with the nerve cells of the grey cerebellar cortex are the numerous receptor axons, which convey proprio-ceptive and cerebral impulses to the cerebellum, and the effector axons of the effector Purkinje cells. Some of the former have been named, on account of their peculiar histological construction, moss fibres and climbing fibres, thus:

Receptor axons.

Moss fibres.

Climbing fibres.

Effector axons.

Purkinje cell axons.

The *moss fibres* are receptor axons, destined chiefly for the innermost or granular layer, upon entering which they break up into a number of end-branches, each of which has a small end-tuft. These end-tufts, which account for the name "mossy fibre," come into relationship with the short dendritic processes of the granule cells. In this way proprio-ceptive impulses coming to the cerebellum are distributed to a large number of granule cells, and thence, by the axons of the latter on to the molecular layer where they reach the Purkinje cells.

The *climbing fibres* are also receptor axons for the conveyance of proprio-ceptive impulses, and were so named by Cajal on account of their tortuous and vine-like course; they ascend through the granular layer to the molecular layer, to which they are chiefly, if not exclusively, distributed, and here they terminate by twining around, and clinging to the primary and secondary dendrons of the cells of Purkinje.

The *effector axons* of the cells of Purkinje have just been described.

Course of Nerve Impulses Through the Cerebellum. From the foregoing account of cerebellar cortical histology it is now possible to understand something of the path of nerve impulses through the cerebellum.

The *moss fibres* comprise receptor cerebellar axons transmitting proprioceptive impulses. They reach the cerebellum, according to Cajal, through the inferior cerebellar peduncles, and terminate in the innermost or granular layer, by forming synaptic contact with the numerous granule cells to which their impulses are conveyed. From the granule cells the impulses are transmitted partly to the Purkinje cells, and partly, though indirectly, to the stellate or Golgi Type II cells. In this way provision is made for the storing up of nerve impulses within the granule cells, and for the stimulation of the greatest possible number of effector or Purkinje cells. There will thus be brought about a general co-ordinative influence over the entire musculature of the body, as is well instanced in the throwing of a ball, in which action there is required a most careful reflex co-ordinative muscular adjustment of the whole body. Through the inferior cerebellar peduncles or restiform bodies are thus conveyed impulses from the proprioceptors of the body, including the receptors in muscles, bones, joints, and the semicircular canals of equilibration.

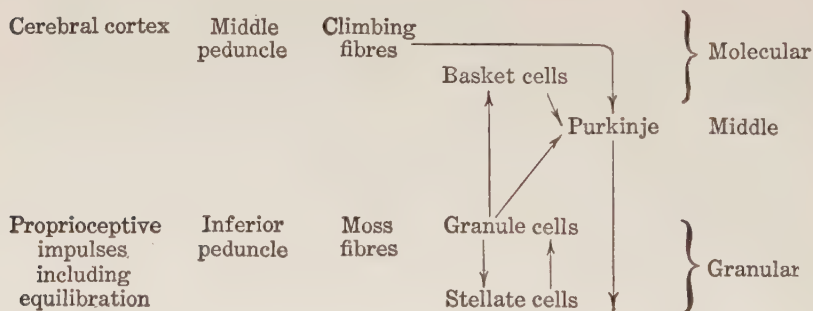
The *climbing fibres* chiefly comprise those axons which enter the cerebellum through the middle cerebellar peduncles. (Cerebro-ponto-cerebellar.) Through them are conveyed impulses from the cerebral cortex, which excite the cerebellum to a discharge of its accumulated nerve energy, and by eventually stimulating the Purkinje cells, serve to co-ordinate the fine adjustments of acts requiring skilled movements in limited groups of muscles.

The Purkinje cells are further, and indirectly, stimulated by the *basket cells* of the outermost or molecular layer of the cerebellar cortex. The nerve route here is from the moss

fibres to the granule cells, thence on to the basket cells, and so to the Purkinje cells. It is thus clear that the basket cells form a mechanism whereby nerve impulses may be temporarily arrested in their passage through the cerebellum, that is, provision is made for the storing up of nerve impulses within the cerebellum, which explains the physiological and clinical fact of the reserve nerve energy known to be associated with cerebellar function.

According to Cajal, the probable function of the *stellate* or *Golgi Type II cells* in the innermost or granular cerebellar layer is to provide a continuous circuit from granule cells back again to granule cells, thus increasing the possibilities of nerve impulse storage within the cerebellum.

The following scheme illustrates these probable paths of nerve impulses through the cerebellum:



Minute Connections of the Cerebellum. As the cerebellum is the great co-ordinating central apparatus for all proprioceptive impulses, its neuronic connections are very largely receptor in character and are very numerous. Many of these connections have already been referred to, but may now be gathered together in a general summary.

The *inferior cerebellar peduncles* or *restiform bodies* (see page 182) represent an extensive connection for the transmission of proprioceptive impulses from muscles, joints, tendons, and bones, and possibly also for the simpler exteroceptive impulses from the skin.

The *juxta-restiform* portion of the inferior cerebellar peduncle is more clearly set aside for the important proprioceptive impulses from the semicircular canals through the vestibular nerve of equilibration.

The *middle cerebellar peduncles* or *brachia pontis* (see

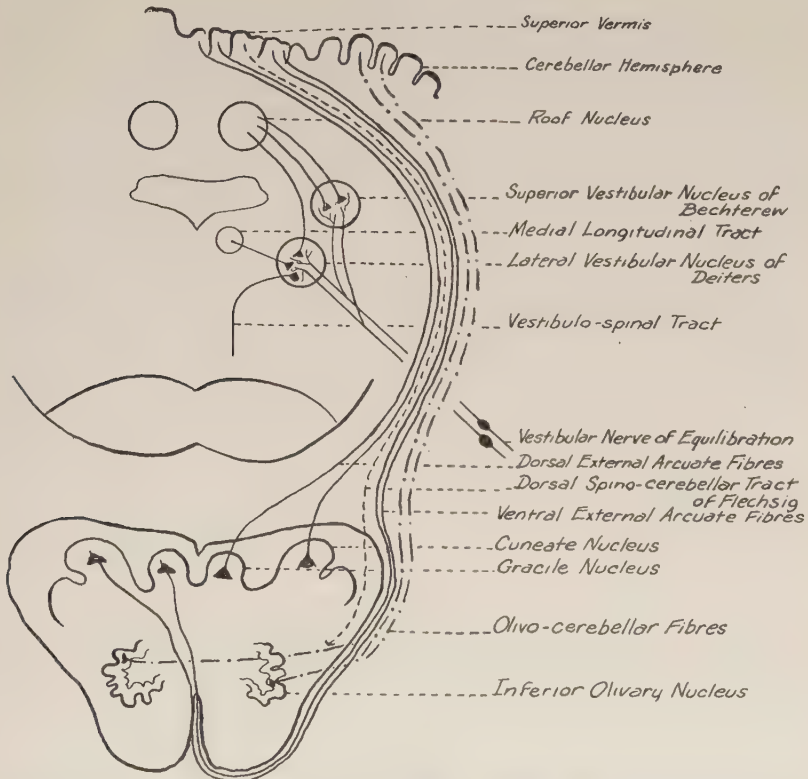


FIG. 77.—Diagram to show proprioceptive tracts entering the cerebellum through the restiform bodies. See pages 104, 107, 129, 182, 188, 207, 284.

page 201) from connections by means of which cerebral impulses are conveyed to the cerebellum from the frontal, temporal, parietal and occipital lobes. The connection is not a continuous one, but is interrupted or "relayed" at the nuclei pontis. The middle cerebellar peduncle is only found in mammals with a neopallial cerebral cortex, and provides, in them,

for the elaboration of visual, auditory, somæsthetic, and kinæsthetic impulses, enabling all these impulses to be correlated in the intricate acts of the balancing of the body in space.

The *superior cerebellar peduncles* or *brachia conjunctiva*, unlike the other two, which are receptor in character, are mainly, if not entirely, effector in function. Within each superior peduncle are two main effector tracts, the cerebello-rubral and the cerebello-thalamic, which are the two main pathways for effector impulses originating within the cerebellum. The axons of which the superior cerebellar peduncles are composed arise mainly in the cells of the dentate nucleus, and terminate chiefly in the red nucleus and thalamus of the opposite side, that is, this peduncle comprises secondary neurons over which effector cerebellar impulses are conveyed, the first series being the Purkinje neurons themselves. These tracts may, therefore, be equally accurately termed dentato-rubral and dentato-thalamic.

The *dentato-rubral tract* comprises the axons of cells situated within the dentate nucleus. These axons undergo decussation within the midbrain (decussation of the superior cerebellar peduncles), give off collaterals to the ocular nuclei, and terminate in the red nucleus; from the red nucleus the impulses are conveyed through the rubro-spinal tract to the spinal cord and so on to the final common effector pathway. As the axons of the rubro-spinal tract also undergo decussation in the decussation of Forel, it follows that the connection between the cerebellum and the spinal cord is an ipsilateral one, and it is by this pathway and its decussation and redecussation, that the cerebellum exercises its control over the muscles of the body of the same side.

The *dentato-thalamic tract* comprises other axons which have their cell stations within the dentate nucleus. They undergo decussation within the midbrain, encapsulate the red nucleus and pass to the thalamus of the opposite side. This tract is, therefore, a link in the cerebello-cerebral pathway. Some of these axons may possibly terminate in the red

nucleus, and pass thence to the sub-thalamic region through a secondary series of neurons.

The *superior cerebellar peduncle* is, therefore, the main effector cerebellar pathway, by means of which it exerts its pro-

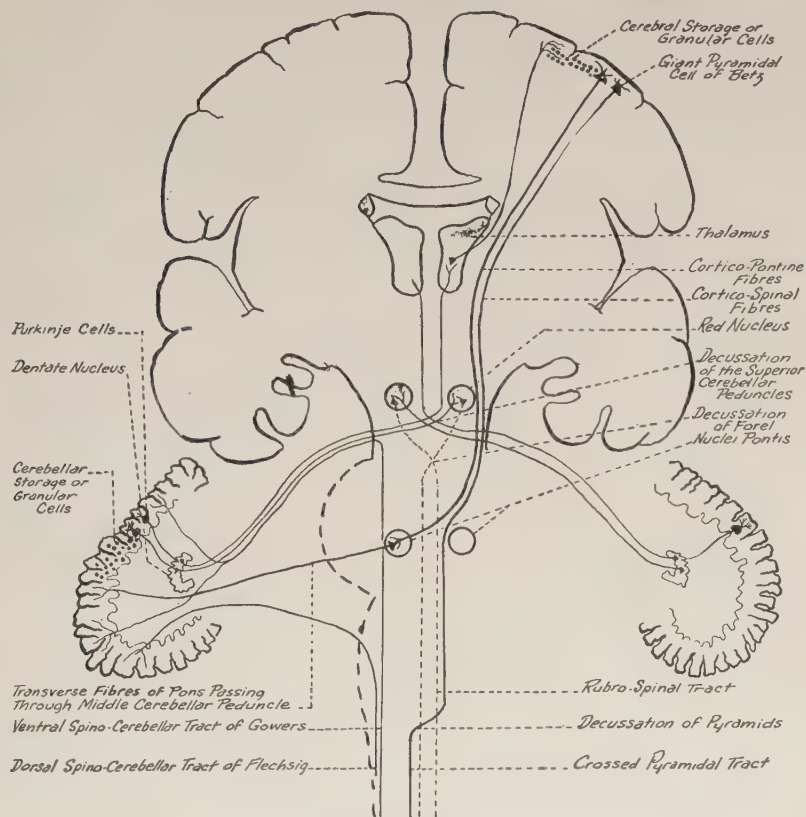


FIG. 78.—A diagram to illustrate some of the principal cerebellar connections. See pages 104, 182, 200, 226, 282, 354.

found influence on all voluntary muscles, and links up its receptor impulses with the cerebral cortex. It does not, however, appear that this is the only effector pathway from the cerebellum, for effector axons appear to arise in the roof nuclei of the same and opposite sides, and pass, probably through all three cerebellar peduncles, to the reticular formation of the pons and medulla. Some of these axons tend

to be specially collected together to form a *fastigio-bulbar tract*, included in which are effector neurons passing to the lateral vestibular nucleus. (Deiters.)

According to Strong the superior cerebellar peduncle is the main effector pathway from the cortex of the cerebellar hemisphere, and the fastigio-bulbar tract that from the vermis.

Lastly, it is to be noted that the ventral spino-cerebellar tract of Gowers enters the cerebellum either in, or closely associated with, the superior cerebellar peduncle, and that Edinger describes a *tecto-cerebellar tract* arising in the tectum of the midbrain and passing to the cerebellum through this same peduncle. It probably conveys impulses from the lower visual centres to the cerebellum.

Functions of the Cerebellum. The functions of the cerebellum are admirably summarised by Herrick as follows:

"The cerebellum is an 'overlord' which dominates the proprioceptive functions of the body in somewhat the same way that the cerebral cortex directs and controls the exteroceptive reactions. Both of these organs are secondarily added to the more primitive segmental structures of the brain-stem, that is, they are supra-segmental.

"The correlation centres of the brain-stem, and particularly those of the cerebral cortex, analyse the receptor impulses entering the brain and determine what particular reactions are appropriate in each situation. After the character of the movement has been determined in this way, the proprioceptive systems co-operate in its execution, and the cerebellum is the central co-ordination station for the proprioceptor reactions. None of its activities come into consciousness.

"The cerebellum, therefore, is intimately connected with all receptor centres which are concerned in the adjustment of the body in space and motor control in general. The maintenance of muscular tone and of bodily equilibrium are the most important of these functions, and the semicircular canals of the internal ear are the receptive organs which are of chief importance in these reactions. . . . The connections of the cerebellum illustrate some of the pathways by which the cere-

bellum is able to reinforce, co-ordinate, or otherwise modify the somatic motor mechanisms. There is an immense amount of potential nervous energy always available in the neurons of the cerebellar cortex, and the cerebellum appears to be constantly exerting a stimulating or tonic effect upon the body muscles. An injury to the cerebellum (especially an asymmetric lesion) produces motor inco-ordination, and the total removal of the cerebellum results in loss of muscular tone and great weakness, though there is no abolition of any particular motor functions. The cerebellar cortex and the cerebral cortex are very intimately connected by large fibre tracts, and each apparently exerts an important physiological effect upon the other. But the exact nature of this reciprocal control is still obscure.

"The cerebellar cortex differs from the cerebral cortex in the form and arrangement of its neurons and further, in that it is structurally similar throughout its entire extent. The cerebral cortex, on the other hand, shows differences in the forms and arrangements of its neurons in different regions, and this is correlated with a regional localisation of diverse functions. There is some evidence that different parts of the cerebellar cortex exert a dominant regulatory influence over particular large groups of muscles; but this localisation of function is of a very general sort and is by no means so precise as the localisation of voluntary motor centres in the cerebral cortex. Moreover, the physiological influence of the cerebellum upon movement is of a very different sort from that of the cerebral cortex."

Cerebellar cortical histological construction is, therefore, such as to compel the conclusion that provision is here made for the diffusion, storage, and re-inforcement of stimuli during the process of their transmission through the cerebellar cortex, for prolongations of "motor" or effector reactions which would otherwise soon subside, and for the maintenance of muscular tone. This type of reinforced nerve reaction has been termed "avalanche conduction." It is probable that the reciprocal relation between the cerebellum and the cerebral

cortex is of a similar sort, all cortical activities exciting the cerebellum, or charging its internuncial neurons, and drawing therefrom additional nervous energy when and as required for the maintenance of the tone of the re-acting mechanism. Voluntary movements excited by the cerebral cortex and transmitted through the cortico-spinal pyramidal tracts are under especially direct proprio-ceptive control from this cerebellar source.

Cerebellar Synergia. That the cerebellum is an organ essential to motor or effector control is the principal conclusion of all observers, or in the words of Mills and Weisenburg, "asynergia is the fundamental symptom of all cerebellar disease." Babinski says, "every form of active muscular exertion necessitates the simultaneous co-operation of immense assemblies of synergic movements throughout the body to secure steadiness and maintain general equilibrium." *Synergia* is, then the power or faculty by which movements more or less complex, but functionally definite, are associated in special acts. In a broad sense it is a motor or effector association, this association being carried out in movements of different parts of the same limb or in synchronous movements of the limbs, of the limbs and head, or of the trunk, limbs, and head together. (Tilney and Riley.)

Loss of this power, or *asynergia*, is the fundamental symptom of cerebellar disease. Clinically, this will manifest itself in a variety of ways, such as a staggering gait, improper measurement of volitional movement, inability to perform succession movements, tremor, irregular persistent nystagmus or oscillation of the eyeballs. Atonia, and asthenia, which are only occasionally present in cerebellar disease, are really secondary disturbances, consequent on the involvement of adjacent structures, and are most commonly found in the more acute forms of cerebellar disease, such as tumours, abscess, gunshot wounds, and inflammation. They are both secondary effects of asynergia and are not to be accounted as primary symptoms of cerebellar disease.

Atonia thus denotes a want or diminution of muscular tone

or power, whilst *asthenia* denotes a lack of strength or general debility. The former may manifest itself, for example, in alterations in the knee jerk, which may change from day to day, being absent one day, normal the next, and excessive on another day.

Asthenia may assume the form of a weakening of the grip, of a tendency to fall when standing, or of a drooping of the head on the side of the lesion.

From the clinical standpoint, it must be further noted that the influence of each bilateral half of the cerebellum is chiefly exerted on the same side of the body, in contradistinction to that of the cerebrum, where each half mainly governs the opposite side of the body. Tumours and other diseases of the cerebellum tend, therefore, to produce symptoms on the same side of the body as the lesion.

Evolutionary History of the Cerebellum. The foregoing account of the minute structure and functions of the cerebellum is, in the main, supported by comparative anatomy, development, experimentation, and clinical medicine.

A cerebellum is present, in some form or another, in all vertebrates and even in some invertebrates, and is, therefore, an organ of great antiquity. Animals which are capable of limited and simple movements possess a small and simple cerebellum, whereas animals having a wide range of motor activity, such as birds, mammals, and man, possess a highly developed cerebellum. In all mammals the essential anatomical elements of the cerebellum are the vermis, hemispheres, rudimentary flocculus and the paraflocculus, and these several parts will differ in their size and complexity, according to the requirements of the animal.

In *mammals* the cerebellum is developed to a higher degree than in lower animal forms. The lateral expansions of the primitive lateral evaginations form the cerebellar hemispheres of the mammals, and this addition is correlated with the much more complex and skilled movements which have to be performed by the mammalian limbs. This naturally attains its highest development in man, and consequently the cerebellar

hemispheres are, in him, larger and more complicated than in any other animal. Experimental studies have further shown that whereas the lateral lobes or hemispheres are the latest evolutionary additions to the cerebellum, and consequently control movements of limbs, the vermis or oldest phylogenetic portion of the cerebellum, is mainly concerned

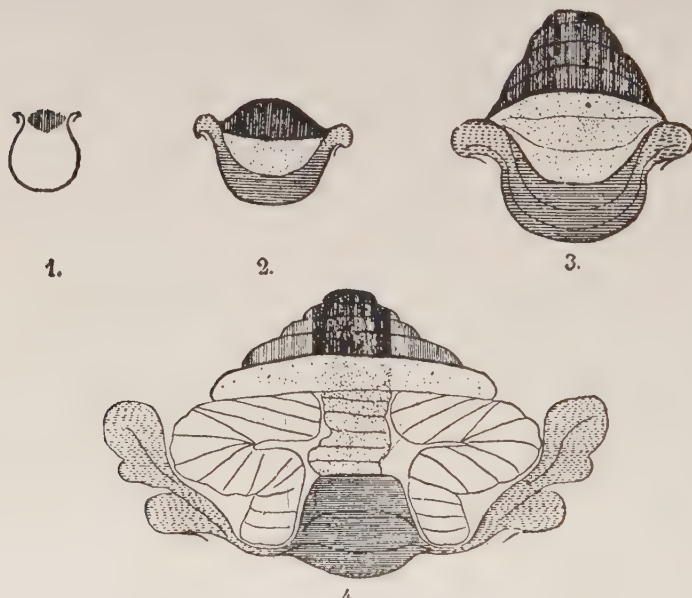


FIG. 79.—Schematic drawing of the cerebellum of: 1, lizard; 2, crocodile; 3, bird; 4, mammal. Vertical lines, anterior lobe; stipple, middle lobe; horizontal lines, posterior lobe; white, lobus ansoparamedianus. (Ingvar.) (From: Ranson, "The Anatomy of the Nervous System.")

with the control of bilaterally synergic movements of the eyes, jaws, neck, and trunk, which are attributes of many of even the lower forms of animal life. In man, however, the vermis also serves, in addition, to control bilaterally synergic limb movements.

Histologically, the cerebellum presents a striking uniformity in structure in almost all animals, and is so different in structure from all other parts of the central nervous system as to be strongly suggestive of a definite specialisation of function which has been present almost from the first in all vertebrates. The type of construction is the *three-layered*

cortex, with an inner granular layer composed of small internuncial neurons and receptor axons; a middle single-celled layer composed of effector Purkinje cells; and an external molecular layer, again composed of small internuncial neurons and receptor axons.

Summary. From the evolutionary standpoint, the cerebellum has been provided as an organ of association for all those receptor impulses which are necessary for the maintenance of the muscles of the body in a state of synergy. "The vestibular apparatus and the cerebellum are genetically and physiologically very closely related. The semicircular canals

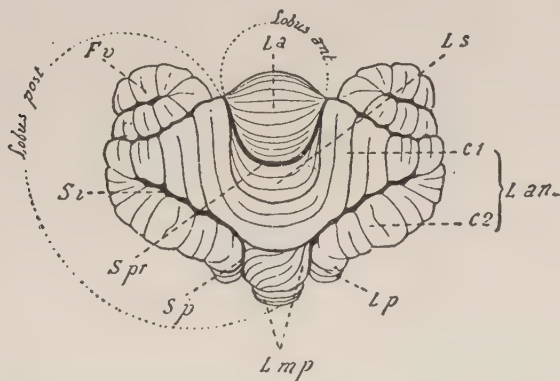


FIG. 80.—Lobular division of dog's cerebellum. (Bolk) (From: Luciani, "Human Physiology.")

are the most highly differentiated proprio-ceptor end-organs, serving chiefly the functions of equilibration and the maintenance of muscular tone. These reactions are, for the most part, unconsciously performed and there is no important cortical path from the vestibular nuclei. These nuclei effect reflex connections with the motor (effector) centres of the spinal cord and medulla oblongata, especially the eye-muscle nuclei, and with the cerebellum.

The cerebellum has been developed out of the primary vestibular area (equilibration) for the more perfect co-ordination and integration of the bodily effector reactions and for strengthening those reactions. It receives receptor impulses from all bodily receptor centres, and in mammals it is also

very intimately connected with the cerebral cortex, these two higher centres—brain and cerebellum—always appearing to act conjointly.

“The cerebellum discharges into all bodily effector centres and assists in preserving the proper balance of muscular contraction and in the maintenance of muscular tone.” (Herrick.)

CHAPTER XXI

THE DIENCEPHALON OR INTERBRAIN

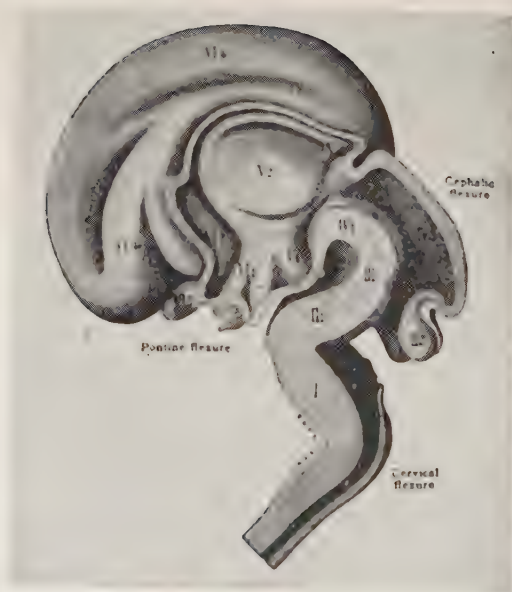
Evolution and Development of the Interbrain. The diencephalon or interbrain forms, in mammals and man, a connecting link between the midbrain and the cerebral hemispheres.

From the evolutionary standpoint, the interbrain was designed, like the midbrain, as an organ for the correlation of nerve impulses, and has played an important evolutionary part in telencephalisation, or the shifting forward of function to the neopallial cerebral hemispheres. In animal forms lower than mammals, such as reptiles, where there are no neopallial cerebral hemispheres, the interbrain forms the receptor "endbrain." With the subsequent addition to the prosencephalon of a neo-pallial cerebrum, as in mammals and man, many of the primitive functions of the interbrain have been transferred thereto, and the diencephalon thus becomes covered from view, and appears, owing to the excessive overgrowth of the neopallial cerebral hemispheres around it, to occupy a central position in the adult human brain. In this extension and folding back of the neopallial cerebral hemispheres over the interbrain, there is formed the *transverse cerebral fissure*, which separates the two.

Cross sections through the developing diencephalon at the end of the third month show it to be composed of a pair of plates on each side, which, with a roof and floor, form the walls of the third ventricle. The dorsal lamina is known as the *alar plate*, the ventral as the *basal plate*, and on either side these meet at an angle, which is termed the *limiting sulcus*. From these several developmental parts are formed the por-



a



b

FIG. 81.—*a*, Median sagittal section through embryonic human brain at end of first month. (After His.) *b*, Sagittal section of brain of human embryo of the third month. (After His.) (From: Morris, "Human Anatomy.")

tions of the adult interbrain, as explained in the following paragraphs.

Constituent Parts of the Primitive Interbrain. The constituent parts of the primitive interbrain, with their modified representatives in the human brain, may be summarised as follows:

The *epithalamus* or *roof of the interbrain*. The non-nervous membranous roof of the interbrain is represented by the *velum interpositum*, which covers in the third ventricle or cavity of that part of the neural tube from which the interbrain is developed. The *pineal body* or *epiphysis*, which diverges along two different lines of evolution, becoming either

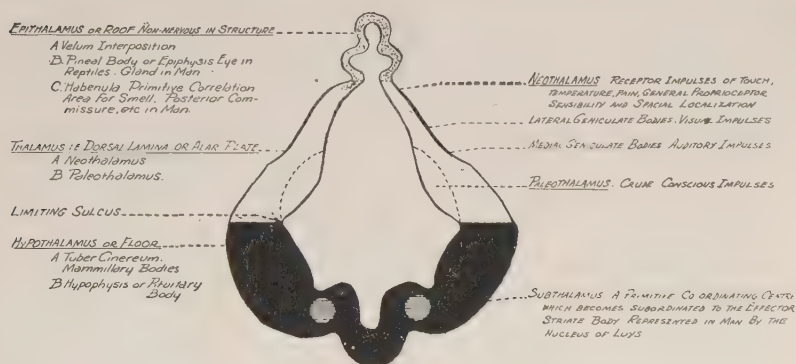


FIG. 82.—Diagrammatic cross section through the diencephalon or interbrain of a 13.8 mm. human embryo to show the developmental parts and the structures developed from them. See pages 52, 295, 299ff.

visual in function as in some of the reptiles, or a ductless gland with an internal secretion as is the case in man. The *habenula*, a primitive area for the correlation of olfactory receptor impulses with the various somatic receptor areas in the dorsal part of the thalamus, is represented in man, by the posterior commissure and associated regions of the human brain.

The *thalamus* or *lateral wall of the interbrain*. The thalamus is developed from a thickening in the alar lamina or alar plate, and is hence receptor in function. It is separated from

the hypothalamus or basal lamina by the limiting sulcus, and in the process of evolution has undergone much alteration. The *paleothalamus*, or oldest evolutionary part of the thalamus, is represented, in man, by the medial group of thalamic nuclei. In animals which lack a neopallial cerebral cortex, such as fishes and other lower vertebrates, the paleothalamus is the chief correlating brain for all incoming receptor stimuli. Many of these primitive functions are retained in the human thalamus, and some conscious activities are still mediated in the thalamus of man, particularly, perhaps, reactions to the cruder forms of pleasurable and painful stimuli. The *neothalamus*, or newer thalamus, is a later evolutionary addition to the thalamic nuclei. It is represented, in man, by the lateral, ventral, and posterior thalamic nuclei. It receives receptor impulses of touch, temperature, pain, general proprioceptive sensibility, spacial localisation, etc., through the spinal, trigeminal, and medial fillets. The *lateral geniculate bodies* and the *pulvinar* receive visual receptor impulses through the optic tracts. The *medial geniculate bodies* receive auditory receptor impulses through the lateral fillets.

The *hypothalamus* or *floor of the interbrain*. The hypothalamus or floor of the interbrain is developed from the basal plate and is, therefore, the only part with effector functions, and even these are, in man, of but little significance. From this portion of the interbrain there are formed the *pars mamillaris hypothalami* and the subthalamus. The *pars mamillaris hypothalami* comprises the mammillary bodies, the tuber cinereum, the infundibulum, and the dorsal lobe of the hypophysis or pituitary body, of which the first three are, in man, of little importance, as they are associated with the feebly developed sense of smell. The *hypophysis* or *pituitary body* is a ductless gland with an internal secretion, which is apparently of importance in maintaining the proper balance of the metabolic activities of the body. The *subthalamus* is situated between the thalamus and the tegmentum of the mid-brain and forms a zone of transition between these two structures.

Such being the principal parts of the interbrain in man it is to be distinctly understood that this is a part of the neuraxis which has undergone considerable change and modification, both structurally and functionally, in the process of evolution. Its constituent parts differ very considerably in different vertebrates according to the functions to be performed and the presence or absence of a true cerebral cortex. In man, where the cerebral cortex has attained its highest development, the functions of the primitive interbrain are largely, but not entirely, taken over by the cerebral cortex, and it thus follows that, with the exception of the thalamus, the structural parts of the human interbrain are of relatively little importance. If, however, the functions of the human interbrain are to be understood, it is essential to know something of the parts concerned, hence the brief description which follows.

The Epithalamus or Roof of the Interbrain. The epithalamus or roof of the interbrain is very largely non-neuronic in structure and from it have been derived such structures as the *pineal body*, which has either become a gland of internal secretion, or an eye-like structure. The view that the pineal body of man, or the mammal, is the vestige of a parietal eye cannot be accepted. It is a gland which, in some animal forms, contributes its secretion to the cerebro-spinal fluid, but in higher vertebrates, including man, has become an endocrine organ, contributing the products of its secretions to the blood stream. These two diverse types of development of the pineal body are, therefore, adaptive modifications to the requirements of the animal, and are in response to its special needs.

The chief parts of the *epithalamic* human interbrain are:—the pineal body, the tela chorioidea of the third ventricle (velum interpositum), and the posterior commissure.

With the exception of the pineal body, the functions of which have been generally indicated, the remaining parts of the epithalamus, together with the associated medullary stria and the habenular triangle are concerned with the sense of smell, which in man is in an atrophied condition and is of little moment.

As regards the *pineal body*, it has, in early life, a glandular structure and appears to attain its greatest development at about the seventh year of life. After this period, and particularly after the age of puberty, it undergoes a process of involution, during which the glandular structure gradually disappears, and is replaced by fibrous tissue. Diminished activity of the gland during childhood would appear to result in an accelerated development of the reproductive organs, with a coincident mental precocity and an increased growth of the skeleton. The inference is, therefore that in the young child the pineal gland furnishes a secretion which inhibits growth and particularly restrains the development of the reproductive organs, though this inference is not finally established.

The Thalamic or Lateral Wall of the Interbrain. The thalamic or lateral wall of the interbrain is developed from the alar plate and is, therefore, receptor in function. It comprises the thalamus and the metathalamus. In the lower vertebrates the thalamic part of the interbrain is insignificant, but in mammals and man, consequent on the shifting forwards of functional areas to the neo-pallial cerebral cortex, it has become the most conspicuous part of the interbrain, inasmuch as almost all receptor impulses are here "relayed" on their onward path to the cerebral cortex. It consequently follows that the thalamus has undergone much change in the process of evolution.

The *primitive thalamus* or *paleothalamus* was, originally, a simple collection of nuclei situated in the grey matter of the third ventricle, that is, of the ventricle developed in connection with the diencephalon. It served for the association and correlation of all incoming receptor impulses and was the final "endbrain" for that purpose, inasmuch as there was, as yet, no neopallial cerebral cortex beyond it. The proper co-ordination of all these "sensory" or receptor impressions in the thalamus resulted in a generalised animal sense of "well-being." Disturbances of these centrally co-ordinated impulses, all of which are of the usual neuronic arc character, either

alter the behaviour and reactions of the animal, man included, or result in the manifestations of loss of function, that is, disease. Hunger, for example, is a change in this sense of well-being. It results from a combination of splanchnic and somatic receptor impulses, which passed, primitively, only to the thalamus, as there was no cerebral cortex, and did so over the receptor arms of the neuronics concerned. Over the effector arms of the neuronics pass the instinctive impulses, which compel the animal to seek food wherewith to allay the sensation of hunger so generated. Reflexes of this character are very numerous in all animal forms, and comprise many arising from either general or somæsthetic sensibility; others are of a protective nature, and still others have to do with the sexual emotions and the desire for the reproduction of the species.

With the evolution of the neo-pallial cerebral hemispheres, many of these primitive co-ordinating functions originally subserved by the thalamus have either been taken over by the cerebral cortex, or have been passed over an increased number of neuronics paths, between thalamus and cortex, and between different portions of the cortex, thereby arousing impressions of memory of previous reflexes. To this category belong many of the primitive emotional reflexes, and if they be largely uncontrolled through insufficiency of thalamo-cortical neuronics connections, or a lack of the controlling supra-granular cells of the brain, they will produce those numerous manifestations of emotional and hysterical conditions so frequently seen in everyday life.

"The paleothalamus seems to be best calculated to serve as the general receptacle for all types of sensibility. It has ancient connections with the end organ of vision, hearing, smell, taste, and also with the receptors of body and visceral sensibility. Having a common assembling ground in the thalamus, the receptor impulses from the entire body may participate in the regulation of the primitive feeling-tone. The combinations of such impressions producing specific phases of feeling-tone may rightly be regarded as the essence

of the primitive emotions. Their persistence in the higher forms of animals is not difficult to discern. They have been attributed to the paleothalamus, as this part of the brain seems to be invested with a functional responsibility related to the development of the emotions and emotive expressions." (Tilney and Riley.)

The *neothalamus* or *new thalamus* is represented in man by the lateral, ventral, and posterior nuclei of the thalamus, which act as relay stations in the pathway of receptor impulses to the cerebral cortex.

The *metathalamus* comprises the geniculate bodies, and fulfills in man the functions of relay stations for the centrally directed axons of hearing and vision. The lateral geniculate body is the older and more important of the two, inasmuch as it is concerned with vision and light reflexes.

The Thalamus in Man. In man the thalamus is the most important functional part of the interbrain, and a knowledge of its evolutionary history, structure, functions, and diseases is essential to a correct appreciation of the phenomena of mind and of diseases of the nervous system.

As seen in the human brain the *thalami* assume the form of two ovoid masses of grey matter which lie obliquely across the path of the peduncles of the cerebrum and on either side of the third ventricle. Each thalamus presents for examination two extremities and four surfaces.

The *lateral surface of the thalamus* is embedded in the cerebral substance, where it is in contact with a thick layer of white matter, the internal capsule, interposed between the thalamus and the lentiform nucleus. From the lateral surface of the thalamus large numbers of fibres pass into the internal capsule, through which they reach the cerebral cortex, and constitute the *thalamic radiation*.

The *medial surface of the thalamus* forms the lateral boundary of the third ventricle, and is, therefore, a free surface, and is visible in any median section of the encephalon. It is covered by the ependyma of the third ventricle, and a thick layer of grey matter, which is continuous with the central grey stratum

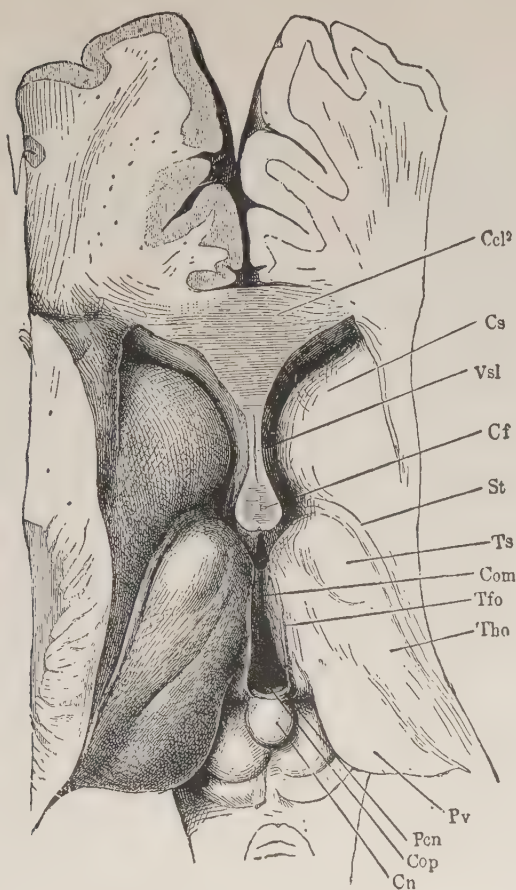


FIG. 83.—View from above of third ventricle and part of the lateral ventricles. (Henle.) The brain has been sliced horizontally immediately below the corpus callosum, and the fornix and velum interpositum have been removed. *Tho*, thalamus opticus; *Ts*, its anterior tubercle; *Pv*, pulvinar; *Com*, middle commissure stretching between the two optic thalami across middle of third ventricle; *Cf*, columns of fornix; *Cn*, pineal gland projecting downwards and backwards between superior corpora quadrigemina; *St*, stria terminalis; *Cs*, nucleus caudatus of corpus striatum; *Vsl*, ventricle of septum lucidum; *Ccl*² section of genu of corpus callosum; *Pcn*, pineal peduncle; *Tfo*, pineal stria; *Cop*, posterior commissure. (From: Luciani, "Human Physiology.")

of the midbrain. This surface of the thalamus is connected to its fellow of the opposite side by a very variably developed round band of grey matter, termed the *massa intermedia*.

The *ventricular surface of the thalamus* is, like the medial surface, a free surface, and is visible, in part, in the floor of the lateral ventricle. It is convex and of a whitish hue, due to a thin superficial covering of white matter, the *stratum zonale*. This surface of the thalamus is divided into two areas, intraventricular and extraventricular, by a faint, oblique groove produced by the lateral edge of the body of the superimposed fornix.

The *extraventricular area*, which includes the anterior tubercle of the thalamus, forms a part of the floor of the lateral ventricle, and is covered by the epithelial chorioid lamina and the chorioid plexus of the lateral ventricle. It lies immediately sub-jacent to the corpus callosum.

The *extraventricular area*, which includes the pulvinar of the thalamus, intervenes between the lateral and third ventricles, but takes no part in the formation of either. Resting upon it is the tela chorioidea of the third

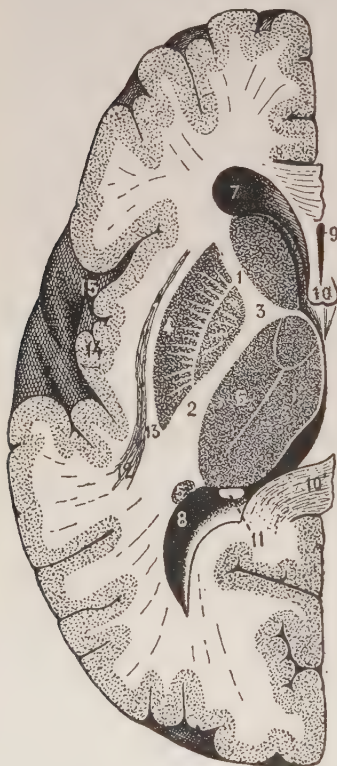


FIG. 84.—Horizontal section of left hemisphere. (Flechsigg.) 1, anterior; 2, posterior limb; 3, genu of internal capsule; 4, nucleus lenticularis; 5, nucleus caudatus; 6, optic thalamus; 7, anterior horn of lateral ventricle; 8, its posterior or occipital horn; 9, septum lucidum and its central cavity; 10, 11, fornix; 10', corpus callosum; 12, claustrum; 13, external capsule; 14, insula; 15, Sylvian fissure. (From: Luciani, "Human Physiology.")

ventricle, on which is the body of the fornix, and on this again the corpus callosum. The extraventricular surface of the thalamus is, therefore, separated from the corpus callosum by the

fornix and the tela chorioidea, whereas the intraventricular part is in direct contact with the corpus callosum.

The *ventral or basal surface of the thalamus* is concealed from view and rests upon the hypothalamus, which separates it from the tegmentum of the midbrain. Many tracts, such as the medial fillet, spino-thalamic, and the superior cerebellar peduncle, enter the thalamus by this surface.

The *anterior tubercle of the thalamus* helps to bound the interventricular foramen of Monro.

The *pulvinar of the thalamus* is the prominent cushion-like projection which overhangs the quadrigeminal brachia. To the lateral side is the lateral geniculate body.

Structure of the Thalamus. The thalamus is a ganglionic mass of grey matter, within which may be recognised a number of nuclear masses. These tend to be separated by strands of white matter, so that the thalamus may be said to be composed of grey and white matter in unequal proportions, the former predominating. The white matter is chiefly found on the ventricular, lateral, and basal surfaces, as also, to a lesser extent, in the interior, whilst the grey matter is mainly found on the medial



FIG. 85.—Thalamencephalon and its relations. Frontal section through grey commissure. (Testut.) *a*, frontal portion of lateral ventricle; *b*, its inferior horn; *c*, third ventricle; *d*, Sylvian fissure; *e*, optic tract; *f*, gyrus hippocampi. 1, lamina medullaris interna of optic thalamus; 2, lamina medullaris externa; 3, internal; 4, external; 5, superior nucleus of optic thalamus; 6, caudate nucleus; 6', its lower end; 7, 7', lenticular nucleus; 8, claustrum; 9, external capsule; 10, internal capsule; 11, pes pedunculi; 12, substantia nigra; 13, stratum dorsale of regio subthalamica; 14, zona incerta; 15, nucleus of Luys; 16, anterior end of red nucleus; 17, great commissure. (From: Luciani, "Human Physiology.")

surface and in the interior in the form of the nuclei mentioned.

From the white *stratum zonale*, which covers the ventricular surface of the thalamus, there projects into the interior of the thalamus a vertical plate of white matter, termed the *internal medullary lamina*. This subdivides the thalamus into three parts, the anterior, medial, and lateral nuclei. The lateral nucleus is the largest of the three and is, in its turn, subdivided into a lateral nucleus proper, and a central nucleus, which is still further subdivided into a central nucleus proper and an arcuate nucleus. The pulvinar forms part of the lateral nucleus.

The *stratum zonale* is largely composed of medullated axons derived from the optic tract, whilst the *external medullary lamina* on the lateral embedded surface of the thalamus is similarly largely composed of axons of the thalamic radiation.

The *central grey matter* which lines the cerebral aqueduct and forms the floor of the third ventricle is continued over the medial surface of the thalamus, and here contains a few scattered nerve cells and axons which probably form a thalamic centre for vasomotor and visceral reflexes, since lesions in this region are often accompanied by disturbances in the nervous control of the blood-vessels and viscera. "If this be true, it is probable that the *dorsal longitudinal bundle of Schutz* (the axons of the cells just referred to which pass down into the floor of the fourth ventricle) serves to bring this thalamic mechanism for visceral adjustments into connection with the visceral effector nuclei of the brain." (Ranson.)

Functions of the Thalamus. The thalamus is interposed in the great receptor pathway to the cerebral cortex, and performs an important part in correlating the activities of the receptor systems. As its various nuclei form abundant connections with the cerebral cortex, they may be regarded as sub-cortical centres, through which occur many reflexes independent of the cortex.

The *primitive paleothalamus* is represented, in man, by the medial and anterior thalamic nuclei. These serve as centres

for the more primitive thalamic correlations, such as occur in lower vertebrates lacking a neopallial cerebral cortex. They receive axons from the olfactory centres and give off axons to the striate body, but none to the cerebral cortex. Clinical evidence would appear to suggest that these thalamic nuclei give rise to a crude form of consciousness, as it has been found that patients in whom the thalamo-cortical connections have been interrupted, are aware of many sensations, but



FIG. 86.—A diagram to show the human derivatives of the old and new receptor thalami, and the old and new effector striate bodies. The globus pallidus is the representative in the mammalian brain of the striate body of lower forms, such as the shark. The claustrum, putamen, amygdaloid nucleus, and greater part of the caudate nucleus are pallial derivatives and are closely related morphologically to the neopallium. See pages 297, 300, 305, 319, 431, 434, 438.

cannot discriminate between them. This portion of the thalamus would also appear to be a centre for the perception of pain and the affective qualities of other sensations, and in this respect plays a rôle in consciousness which is independent of the cerebral cortex.

The *neothalamus* is represented in man by the lateral, ventral and posterior nuclei, the pulvinar and the geniculate bodies, and forms the larger portion of the human thalamus. The several nuclei of which the human neothalamus is composed serve mainly as relay stations on the upward cerebral

path of the somatic receptor tracts. These include the medial fillet for discriminative sensibility and the spino-thalamic tracts for pain-temperature sensibility which terminate in the ventral subdivision of the lateral nucleus. In the pulvinar and lateral geniculate body terminate the retinal fibres of the optic tracts, whilst the lateral fillet for auditory impulses terminates in the medial geniculate body. From these thalamic nuclei the impulses are conveyed on to the cerebral cortex by receptor neurons of the third order. The lateral thalamic nucleus, exclusive of the pulvinar, is, therefore, largely a relay station on the paths of the cutaneous and deep sensibility, and is connected with the parietal and frontal cortex through the axons of the thalamic radiation. There also terminate in the thalamus some of the axons of the superior cerebellar peduncles, as well as some from the red nucleus.

It is thus obvious that most of the great ascending receptor pathways terminate in the thalamus, whence they are relayed on to the cerebral cortex by the ascending axons of the thalamic radiation. That the thalamus gives off some descending axons is also certain, though these have not been as completely established as the other thalamic connections. Amongst these descending tracts from the thalamus may be mentioned the *thalamo-olivary tract*, which passes downwards to the inferior olivary nucleus of the medulla. A *thalamo-spinal tract* has also been described as descending from the thalamus in close relationship with the rubro-spinal tract. It is further known that the axons of the spino-thalamic tract, the trigeminal fillet, and the medial fillet terminate in the neothalamus in that order from the lateral to the medial side, and these positions correspond to those occupied by the same tracts in the tegmentum of the midbrain.

The agreement between the *evolutionary* subdivision of the thalamus into a paleothalamus and a neothalamus and that suggested by Sachs on *clinical* grounds is a remarkable one. Sachs regards the thalamus as being composed of two practically independent functional parts, an inner or medial division, in relation with the caudate nucleus and the rhinen-

cephalon, that is, the paleothalamus, and an outer or lateral division in which terminate the great receptor pathways already described, clearly corresponding to the neothalamus.

Through the *pulvinar* of the thalamus pass some of the fibres of the optic radiation, though as a relay station the pulvinar does not appear to play as important a part as the

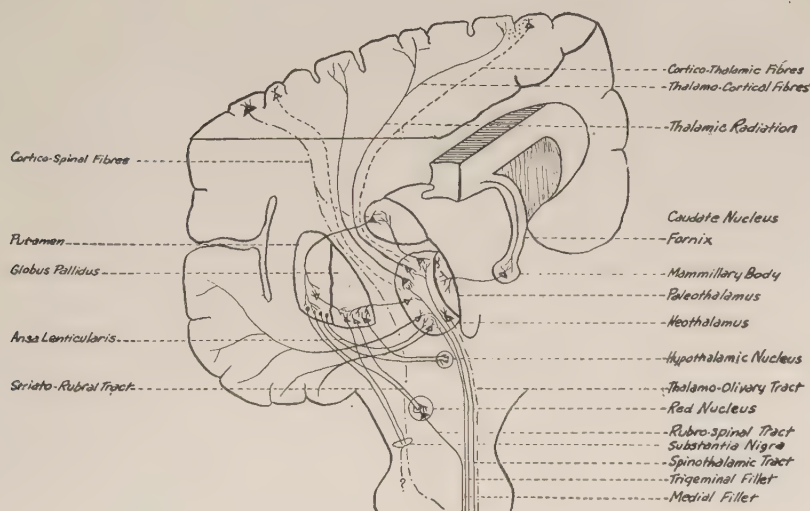


FIG. 87.—A diagram of the principal connections of the receptor thalamus and the effector caudate nucleus and lenticular nucleus. See pages 300, 306, 307, 418, 435, 438.

lateral geniculate body. In any case, lesions of the pulvinar are not so frequently accompanied by hemianopsia.

The last and most important links in the receptor pathways to the cerebral cortex are those numerous neuron connections between the thalamus and practically all parts of the cortex. The thalamus thus establishes thalamo-cortical connections for all the great receptor pathways, except possibly those of taste and smell, with their appropriate areas in the cerebral cortex for their final elaboration in consciousness. It is also connected with the striate body, which is chiefly an effector nucleus, and this link between the receptor thalamus and the effector striate body provides a series of subcortical

reflex neuronie arcs. The thalamus thus establishes two great series of connections, the thalamo-cortical and the thalamo-striate.

The Hypothalamus or Floor of the Interbrain. The hypothalamus or floor of the interbrain was primitively concerned with the correlation of gustatory, general splanchnic, and olfactory impulses, which served the purposes of the animal in selecting and procuring food. With the subsequent evolution and addition of a neopallial cerebral cortex, the transference of these impulses to these newer "brains," and the partial suppression, in man, of such senses as smell and taste, the hypothalamic part of the interbrain has lost much of its original significance.

Developmentally the hypothalamus represents the basal lamina and gives rise to the tuber cinereum, posterior or dorsal lobe of the hypophysis, and the mammillary bodies. *Structurally*, the hypothalamus consists of three parts, the pars optica hypothalami, which really belongs developmentally to the telencephalon, *not* the diencephalon, the pars mamillaris hypothalami, and the subthalamus.

The *pars optica hypothalami* closes in the third ventricle of the interbrain on the forebrain side, consequent on the development of the telencephalon as a later addition to the neuraxis. Developmentally it is, as just stated, a part of the telencephalon, and its detailed consideration is more fittingly given with the third ventricle. The parts included are the anterior commissure, the lamina terminalis, and the optic chiasma.

The *pars mamillaris hypothalami* includes the mammillary bodies, the tuber cinereum, the infundibulum, and the dorsal lobe of the hypophysis. The *mammillary bodies*, associated with the fornix, are two small, whitish, pea-like eminences which lie side by side in the interpeduncular fossa on the immediate frontal side of the posterior perforated substance. Each is composed of a central grey nucleus encapsulated by white matter. The mammillary bodies are part of an unimportant central connection which serves to bring the olfactory

portion of the brain into relationship with the tegmentum of the midbrain. In its more primitive condition this connection probably assisted the animal in the selection of suitable food. The *tuber cinereum* is best seen on the inferior surface of the brain, where it assumes the form of a slightly elevated grey area close to the mammillary bodies. It is one of the olfactory areas, and attached to it is the funnel-shaped stalk of the hypophysis, known as the *infundibulum*. The *hypophysis* or *pituitary body* is a gland of internal secretion, the dorsal lobe of which is developed as an out-pouching from the floor of the interbrain, and is non-nervous in structure.

The *subthalamus* is situated between the thalamus and the tegmentum of the midbrain and thus forms a zone of transition between these structures. The region is traversed by the long ascending tracts which terminate in the thalamus, and the red nucleus and the substantia nigra both project up into it from the midbrain. Below the thalamus, and lateral to the red nucleus, there is found in the subthalamus a grey nucleus termed the *hypothalamic nucleus*. The connections and functions of this nucleus are not thoroughly understood, but it is not improbable that it receives axons from the thalamus, striate body, and pyramidal tract, and sends axons downwards in the cerebral peduncle. In this case the nucleus may be an effector co-ordinating centre for the thalamo-striate brain.

The Third Ventricle. The third ventricle is the cavity of the diencephalon. It assumes the form, in the adult, of a narrow cleft, which lies in the median plane of the body, between the two thalami.

The *floor* of the third ventricle slopes from the occipital end downwards and forwards (caudofrontally); its depth is, in consequence, greater at the frontal end than elsewhere. It is formed by the optic chiasma, the infundibulum, the tuber cinereum, the mammillary bodies, and the subthalamus.

The *roof* of the third ventricle is formed by a thin layer of *ependyma* which is stretched between the medullary striæ of the two thalami. Resting upon this epithelial layer is that

invaginated fold of pia mater, termed the *tela chorioidea*, from the lateral edges of which delicate vascular folds are invaginated into the ventricle, carrying a layer of ependyma with them, so that these vascular fringes are excluded from the ventricular cavity. These fringes are termed *chorioid*



FIG. 88.—Right half of the brain divided by a vertical antero-posterior section (from various sources and from nature). (Allen Thomson.) $\frac{1}{2}$. 1, 2, 3, 3a, 3b are placed on convolutions of the cerebrum; 4, the fifth ventricle, and above it the divided corpus callosum; 5, the third ventricle; 5', pituitary body; 6, corpora quadrigemina and pineal gland; +, the fourth ventricle; 7, pons Varolii; 8, medulla oblongata; 9, cerebellum; I, the olfactory bulb; II, right optic nerve; III, right 3rd nerve. (From: Luciani, "Human Physiology.")

plexuses and they secrete fluid which is poured into the ventricular cavity.

Each *lateral wall* of the third ventricle is bounded by the columns of the fornix and the thalamus, the thalami of opposite sides being connected together across the cavity of the ventricle by the intermediate mass.

The *occipital wall* of the third ventricle is bounded by the pineal body and the habenular and posterior commissures.

The *frontal wall* of the third ventricle is formed by structures developed from the telencephalon, that is, the vesicle

from which the neopallial cerebral hemispheres are developed. These structures are the anterior commissure, the lamina terminalis, and the optic chiasma. The *anterior commissure* is a bundle of fibres which crosses the median plane in the upper part of the lamina terminalis, and forms part of the commissural system of the olfactory archipallium. The *lamina terminalis* is a thin plate joining the two cerebral hemispheres. It stretches from the anterior commissure to the optic chiasma. The *optic chiasma* is formed by the decussation of the optic nerve fibres and projects, as a transverse ridge, into the floor of the third ventricle.

The *third ventricle* is the diencephalic part of the ventricular system of the neuraxis. It communicates with the two lateral ventricles of the telencephalon by means of the interventricular foramen of Monro, and with the fourth ventricle of the rhombencephalon by means of the cerebral aqueduct of Sylvius.

Functions of the Interbrain. It has been shown that the interbrain consists, in both man and the primitive animals, of an epithalamus or roof, of two thalami or lateral walls, and of a hypothalamus or floor. It has also been seen that in the human brain it is the thalamic part which has chiefly retained functional significance, whilst the remaining portions of the interbrain have had their functions largely superseded by the development and addition of another and newer "endbrain"—the telencephalon—from which the cerebral hemispheres have been developed, and to which many of the primitive functions of both midbrain and interbrain have been shifted. It is, therefore, the functions of the thalamus and its connections which it is so important to understand.

Concerning the human thalamus, there is a certain amount of clinical evidence which would appear to show that it possesses motor functions, but there is a much larger amount of evidence to prove the contrary. There is, first, the evolution of the thalamus; second, its histological construction; and third, its connections.

The *primitive vertebrate conditions* of the interbrain go

to prove that the major part of the interbrain in general, and the thalamus in particular, have always been receptor or sensory in character, and have always served for the correlation of such impulses. The sensory nature of the thalamus is also supported by embryology, inasmuch as it is developed from the alar lamina, and not from the basal. It could not, therefore, be motor in function.

The *histological construction* of the thalamus reveals no cell elements representative of effector or motor specialisation. This is equally true of both old and new thalami. The hypothalamus, developed from the basal lamina, is the only exception to this rule in the interbrain region.

The receptor character of the thalamus is also borne out by its *connections*, because it receives all the great receptor tracts, and there is no known effector pathway from the thalamus to the pyramidal effector pathway. All these facts point, therefore, notwithstanding any clinical evidence to the contrary, to the sensory or receptor nature of the thalamus. That many clinicians have recorded cases where lesions of the thalamus have apparently been followed by disorderly movement is undoubted, but this does not prove that the thalamus is motor in character. It merely indicates that the thalamic disease has interfered with the normal reflex arcs through the thalamus, and so permitted an uncontrolled activity of effector neurons over which thalamic influence or control has been removed or interfered with by disease.

That the thalamus is solely receptor or sensory in function is not only proved by the facts adduced, but is also supported by much clinical evidence, so that the clinical evidence really cuts both ways. When the thalamus is the subject of disease there may be forced laughing or crying, automatic screaming, athetosis, chorea and tremor, which means that the neuronic arcs through the thalamus have been disturbed, and the cortical control over the thalamus removed or impaired. The nerve impulses are now passing over the more primitive thalamo-striate arcs with absence or diminution of cortical control.

That some psychic processes representing a certain degree of consciousness may be carried on by the thalamus independent of the cerebral cortex is undoubted. (Tilney and Riley.) There is, therefore, a perfectly effective neurological explanation of many forms of hysteria, neurasthenia, psychoneuroses and other disordered mental conditions. Many of these conditions are induced in cerebrally under-neuroned individuals at periods of life associated with undue stress on the nervous system, and are thus due, not so much to actual disease, as to an imperfectly developed cerebral cortex. It is quite certain that the high-grade ament suffers from these and similar conditions both earlier in life and more frequently than the normal individual or the genius, because his comparative lack of cortical neurons diminishes his natural powers of resistance to the stresses of life referred to.

Certain diseases of the thalamus would appear to interfere with the neuronic arcs from the thalamus to the cortex and thus the nerve impulses are compelled to traverse other arcs with the result that disordered functions manifest themselves. If such disease causes receptor impulses to be switched off from the thalamus directly to the striate body, instead of to the cortex as should be the case, the brain is cut out by the short circuit followed, and there is immediately manifested disordered movement and lack of control from excessive stimulation of the striate body neurons, together with an exaggerated emotional state, for the thalamo-striate brain is the primitive seat of the primitive emotions. In health such impulses should traverse the more recently evolved thalamo-cortical pathways to the cerebral cortex where they are diffused through that cortex, thence from the cortex through the thalamus to the striate body, so bringing the reactions of the thalamo-striate brain under cortical control, with a restraint of the emotions concerned.

The Visual Apparatus. There is but one pair of nerves associated with the interbrain, and these, the optic nerves, are not so much nerves as they are brain tracts connecting the retinae with the occipital cortex.

The *retina* itself is developed as an evagination of the lateral wall of the prosencephalon in the form of a vesicle, the cavity of which is continuous with that of the forebrain, and this developmental fact at once explains why the structure of the retina resembles that of the brain more than does any other receptor organ. The retinal evagination, or *optic vesicle*, undergoes an invagination, that is, a folding of its walls in the reverse direction, and so becomes transformed into a two-layered *optic cup*. From the inner of these two layers are developed the nerve elements of the retina, whilst from the outer layer is developed the pigmented stratum of the retina.

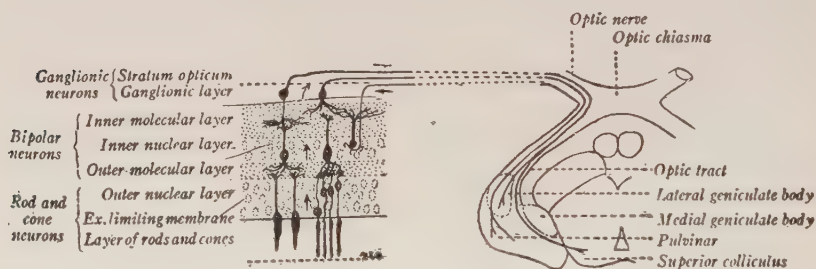


FIG. 89.—Schematic representation of the retina and the connections established by the optic nerve fibres. (From: Ranson, "Anatomy of the Nervous System.")

The retina is composed of three layers of superimposed neurons, some of which are very specially modified to act as the receptor organs of vision. These three layers of cells are the visual receptor neurons, the bipolar neurons, and the ganglion neurons.

The *visual receptor neurons* are very highly modified neurons which serve as the receptor organs of vision. Their dendrons are more usually known as rods and cones, and are thus modified in order to act as the receptors for light stimulation. The axons of these specially modified neurons pass into the outer molecular layer where they establish synaptic contact with the *bipolar retinal neurons*. The axons of the latter terminate in the inner molecular layer, where they establish synaptic contact with the dendrons of the ganglionic neurons.

The axons of the *ganglionic cells* of the retina form the most internal layer of the retina, the *stratum opticum*, through which they enter the optic nerves, the optic chiasma, the optic tracts, and finally terminate in the superior colliculus, the lateral geniculate body, and the pulvinar of the thalamus, which thus act as reinforcing and shunting stations for visual impulses and reflexes. The latter function is chiefly subserved by the superior colliculus, whilst the lateral geniculate body and the pulvinar are the reinforcing stations for the visual impulses which are to be conducted to the occipital cerebral cortex, in which visual impressions arise. The axons of this last series of optic neurons form the *optic radiation* of the cerebral hemispheres. Although their function is not understood, it is also well established that these several optic paths convey impulses from the cortex and lower visual centres back again to the retinae over some corticifugal neurons.

CHAPTER XXII

THE EVOLUTIONARY HISTORY OF THE CEREBRAL HEMISPHERES

The Human Cerebral Hemispheres. The cerebral hemispheres of man are the most striking and distinctive portions of his nervous system. Like the cerebellum and tectum mesencephali, they are supra-segmental additions, and show the same supra-segmental details of construction. By weight and volume the brain represents about 70% of the entire nervous system, and it is this dominance in size of the human telencephalon, from which the neopallial cerebral hemispheres are the most recent derivatives, with the extraordinarily large number of contained neurons, which gives man his pre-eminence in the animal kingdom, and to which he owes his individuality, his mentality, and individualistic behavioural reactions. To the fashioning of neopallial cerebral hemispheres from the telencephalon a long series of evolutionary changes have contributed.

Evolutionary History of the Telencephalon. The telencephalon is the most cephalic of the cerebral vesicles and results from the subdivision of the prosencephalon into telencephalon and diencephalon. In its most primitive form, as, for example, in the *cyclostomes*, the telencephalon consists of an *olfactory bulb* connected with an olfactory lobe, which is a single undivided structure. In the floor of the telencephalon is a special collection of neurons, the *epistriatum*, which receives fibres from the olfactory lobe, connected, in its turn, with the olfactory bulb. The *epistriatum* is, therefore, the forerunner of the olfactory archipallium. In the floor of this primitive telencephalon is a collection of large pyramidal motor or effector cells, which collectively make up the primitive *striate body*. This primitive striate body is connected

with the primitive thalamus of the interbrain, to which pass visual, gustatory, and somæsthetic impulses, and with the epistriatum, to which pass olfactory impulses. It thus acts as the effector brain, through which the various sensory impulses are transformed into somatic motor activities. The behaviour of the cyclostome is thus of a purely generic type. It maintains its own life, and propagates its species, but has nothing of an individualistic nature in its reactions to the environment. All that remains of the walls of the telencephalon in such animals is non-nervous in structure, and thus the primi-

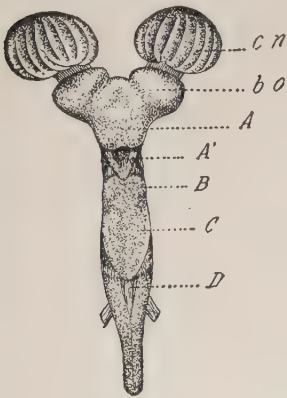


FIG. 90b.—Brain of *Scylium canicula*. (Steiner.) *cn*, nasal capsule; *bo*, olfactory bulb; *A*, prosencephalon; *A'*, optic thalami or tween-brain; *B*, optic lobes or mid-brain; *C*, metencephalon or hindbrain; *D*, myelencephalon or bulb, from which the vagus nerve emerges. (From: Luciani, "Human Physiology.")

tive telencephalon possesses an olfactory bulb, an epistriatum, and a striatum. There is no pallial cortex whatever.

In fishes, like the teleosts and ganoids, the telencephalon shows little structural advance on the cyclostomes, though the appearances differ somewhat, owing to the olfactory bulbs becoming farther removed from the olfactory lobe, though still connected thereto by the olfactory stalk, the forerunner of the olfactory tract. These slight changes apart, the telencephalon still consists of the olfactory lobe, olfactory bulb, epistriatum, and

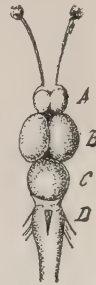


FIG. 90a.—Brain of *Squalius cephalus* (Steiner.) *A*, prosencephalon, with olfactory nerve above; *B*, mesencephalon or optic lobes; *C*, metencephalon or hind-brain; *D*, myelencephalon or bulb. (From Luciani, "Human Physiology.")

corpus striatum, roofed in by a non-nervous membrane, part of the undifferentiated wall of the telencephalon itself. The type of behaviour is still characteristically generic.

In amphibians, for the first time, the telencephalon becomes partially divided into two—the forerunners of the two cer-

eral hemispheres—but the olfactory lobes do not participate in this sub-division. Each half of the amphibian endbrain now consists of a partially differentiated hemisphere, with an olfactory bulb, an olfactory lobe, an epistriatum, and a corpus striatum, but the cells of the epistriatum now begin to invade

the non-nervous membranous roof of the telencephalon and thus forshadow its conversion into, first, an archipallium, and much later, a neopallium.

In *reptiles* this invasion of the telencephalon membranous roof by olfactory neurons from the epistriatum is carried a step farther, and a part of that roof becomes differentiated as an olfactory or hippocampal pallium, and this is sufficiently extensive as to warrant the term of *rhinencephalon* or *smell brain*, which, histologically, consists of five layers and becomes connected to its fellow of the opposite side by crossed fibres, as well as with parts of the same side by short and long association fibres.

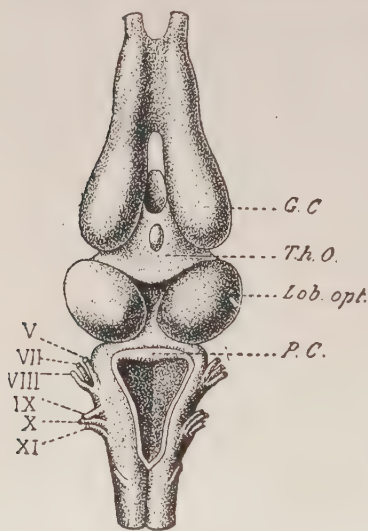


FIG. 91.—Frog's brain—enlarged four times. (Loeb.) *G.C.*, prosencephalon; *Th.O.*, optic thalamus; *Lob. opt.*, optic lobes; *P.C.*, cerebellum, showing medulla oblongata below, whence issue the cranial nerves. (From: Luciani, "Human Physiology.")

The meaning of this striking change in the roof of the telencephalon of amphibians and reptiles is clearly that a cerebral pallium is in process of being added in the interests of expanding olfactory experiences, and provides a more elaborate mechanism for the procurement of suitable food. It has been rendered necessary by the changed medium—air instead of water—through which the olfactory stimuli are now conveyed. In this new and extended form the sense of smell will now serve other purposes besides those connected with food. It will aid the animal in the protective reactions of offence and

defence, as well as for purposes of sex. The behavioural reactions of amphibians and reptiles have become amplified by these additions to the telencephalon, but they still remain generic and manifest but little individual modification.

In *birds* the telencephalic endbrain still consists of two large hemispheres, but the pallium shows little advance on the reptile. The corpus striatum, on the other hand shows a great advance, both in the numbers of its neurons and its subdivision, and it becomes connected with both the pallium and the thalamus, whilst from it there passes a well developed *basal bundle*—the most ancient of the motor pathways, and present in fish, amphibians, and reptiles—and the only motor pathway possessed by such animals. “The great size of the corpus striatum is indicative of the many varieties of generic behaviour manifested by birds. Among these may be mentioned the various behavioural reactions seen in mating, nesting, protection of the young and migration, as well as actions in quest of food, in defence and attack. Almost every species of bird has its series of motor activities which assist in identifying it, and which represent special modifications of generic behaviour. On the other hand, individual differences between birds of the same species are slight.” (Tilney and Riley.)

With the advent of the *mammal* a very great change takes place in the telencephalic roof, and there is formed, for the first time, a neopallial cerebral hemisphere. This new and extended portion is termed the *neopallium*, in opposition to the more primitive olfactory cortex, which is the *archipallium*, and it is brought about in the same way, that is, by neurons which have previously terminated elsewhere, becoming transferred to the roof of the telencephalon, invading it, and so forming the neopallium. “Where the requirements of vision, hearing, and general bodily sensibility, could no longer be satisfied by the primitive mechanism provided for them, their



FIG. 92.—A brain of normal pigeon—from nature, enlarged $\frac{1}{4}$. (From: Luciani, “Human Physiology.”)

sphere of influence was transferred forwards into newer parts of the brain, capable of a greater degree of expansion." (Tilney and Riley.) For example, visual neurons which terminate, in the bird, in the optic lobes (superior quadrigeminal bodies of man) and become considerably increased in numbers in birds, become transferred, in the mammal, to the non-membranous roof of the telencephalon, thus emulating the olfactory neurons which migrated there at an earlier period of evolutionary development. This last addition to the telencephalon has, therefore, followed the law of telencephalisation, which has permitted, or produced, new cortical areas, as the cerebral functions of midbrain and interbrain became shifted forwards. When this has been accomplished it follows that the primitive parts of the telencephalic brain will now consist of a neopallium, an archipallium, olfactory lobe, and striate body.

In the earliest of the mammals, the *monotremes* and *marsupials*, the cortex is still very reptilian in character. The rhinencephalon, which seems to have become suppressed in birds, presumably to make way for the increased numbers of visual neurons, reappears, and the only inter-hemispherical connections are by means of the hippocampal and anterior commissures, the corpus callosum being absent, which raises the interesting problem of the two marsupial hemispheres being mutually independent of each other. Among the *rodents* four distinct functional regions can be located in the neopallial cortex, namely, motor, visual, sensory, and olfactory. In *carnivorous mammals*, motor, visual, olfactory, auditory, and somæsthetic areas can similarly be recognised.

In *all mammals* the neopallial cerebral cortex is a stratified histological arrangement of cells and processes, the primary laminae of which are three in number, and the increase in cortical neurons necessitates a similar increase in the medullated axons of the white cortical matter. This medullary increase serves to associate together the different impulses now reaching the telencephalon, and a large proportion of it is purely associational in character, that is, different parts of the same

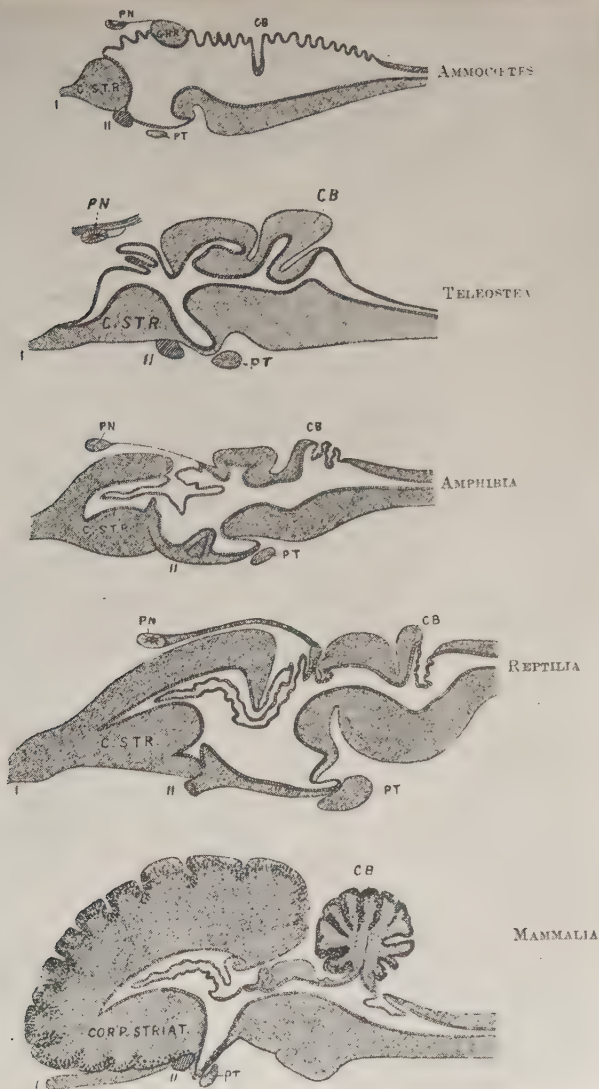


FIG. 93.—Diagrammatic view of the brain in different classes of vertebrates (Gaskell). *cb*, cerebellum; *pt*, pituitary body; *pn*, pineal body; *c.str.*, corpus striatum; *ghr*, right ganglion habenula; I, olfactory; II, optic nerves. (From: Starling, "Principles of Human Physiology.")

cerebral hemisphere are associated together by short and long association fibres. In all mammals higher than marsupials an additional correlation is established by the provision of *commissural* neurons linking together the cerebral hemispheres of opposite sides, that is, a corpus callosum makes its appearance, and lastly, as the neopallial cortex has now assumed functions previously undertaken by lower parts of the neuraxis, such as the inter- and midbrains a third series of neurons, termed *projection*, becomes necessary in order to link up the cerebral hemispheres with the lower parts of the neuraxis, and these become specialised into functional groups, some conducting towards the cerebral cortex, others away from it. Associated with these changes in the telencephalic neopallial cortex, the thalamus and striate body undergo great changes. Additions are made to both these structures and their primitive functions are, to a certain extent, taken over by the cortex.

Provision is next made for an increase in the numbers of neurons in the telencephalic cerebral cortex, and this is first brought about by convoluting the surface. In most of the lower mammals the cerebral surface is not convoluted but is smooth. Such cortices are termed *lissencephalic*. Most of the higher mammals have a convoluted or *gyrencephalic* cerebral cortex, an arrangement which obviously increases the numbers of contained cortical neurons. The rabbit is an example of the former, and the dog of the latter, and the greater individuality of the dog, as compared with the rabbit, is clearly due to the increased number of cortical neurons permitted to the dog by its gyrencephalic cortex.

With the anthropoid ape the cortical neurons become still further increased by the addition to the cortex of apparently non-functional areas interposed between the functional areas and termed *association areas*. As will be seen later, so far from being functionless, these association areas are the forerunners of the human mind. There also commence to be added to the cortex generally, the association areas included, additional layers of neurons on the exterior, so that the origi-

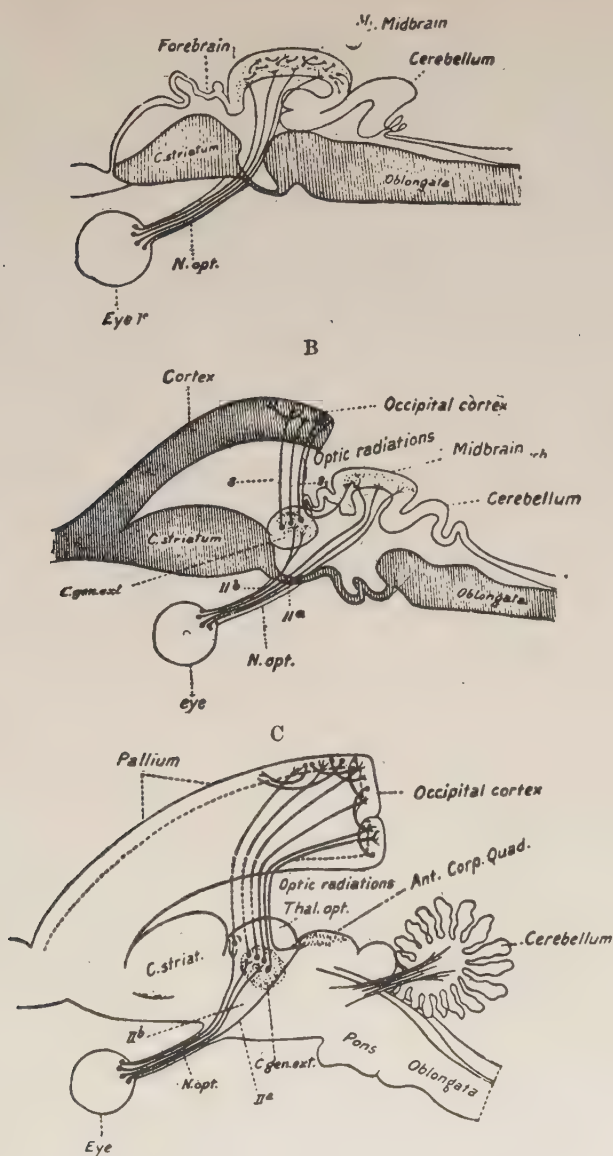


FIG. 94.—Diagrams from Monakow, showing the evolution of the neopallium and the gradual shifting of the visual sensory tracts from the mid-brain to the fore-brain, and thence to the occipital cortex. A, a bony fish; B, brain of a lizard; C, brain of a mammal (cat). (From: Starling, "Principles of Human Physiology.")

nal tri-laminar mammalian cerebral cortex becomes converted into one with five primary laminæ.

With these successive additions to the telencephalic neopallial cortex the behaviour of the animal becomes less and less generic in type, and more and more individualistic. The extent to which the dog and other lower mammals can be trained is well known, whilst the still higher chimpanzee, with still more cortical neurons, becomes, apart from speech, almost human in its individualistic behaviour.

The Human Brain. With each successive evolutionary phase the histological construction of the neopallium becomes more complex, that is, there is an ever-increasing number of neurons and neuronics arcs. This culminates in man, where all the cortical areas of the lower mammals are retained, but are widely separated from each other by still more additional areas of cortex termed *association areas*, in which, there can be no reasonable doubt, occur many of those mental phenomena, such as judgement, ideation, reason, intellect, and so on, which form the chief and most striking differences between man and the lower animals, and alter the reaction to the environment from generic to individualistic. To make way for these additional cortical areas, the rhinencephalon or smell brain has, in man, been largely suppressed. It is, however, important to remember that the thalamus and striate body are retained in a form of functional activity, and through them occur many of the reactions of generic behaviour, controlled, when the neuronics mechanism is sufficiently developed, by the cerebral cortex. When not so controlled, the human behaviour may become so modified as to give rise to aberrant behaviour which, in the interests of others, requires the segregation of the individual.

Increments in Telencephalic Cortical Neurons. Comparative anatomy thus proves that a progressive increase in size and complexity of the encephalon or brain is a noticeable and striking feature with evolutionary progress from the fish to the amphibia, and thence through reptiles, birds, and mammals to man. In man the brain has attained its highest

development; the human brain differs from that of all other animals in its large size (being from two and a half to three times larger than the brain of other animals); in the complexity of the fissuring of the surface (gyrencephalic), which increases the number of cortical neurons; in the possession of large association areas, larger even than the anthropoid ape, which again increase the number of neurons, and in the addition of a still further large number of pyramidal cells (the supra-granular cortex) to the external part of the cerebral cortex. With all these successive increases in size, prominence, and complexity, the nervous system has gradually become transformed from an organ for the translation of a few simple stimuli into purposive reaction, into one of mind and intelligence, but the structural process by which this is accomplished is always the same, namely, a constant addition of neurons and their combination into arcs. With each successive addition to the primitive segmental equivalent of a spinal cord, these neuronie arcs become more and more complex, and reach their culmination in the cerebral cortex of man.

Ontogeny Reproduces Phylogeny. Every human individual passes, during the prenatal and postnatal stages of growth, through these evolutionary steps. He reproduces in his own history that of his ancestors. His subsequent behaviour, as an adult, will depend on the degree of development which his cortical neurons attain. His "intelligence" will depend on the number, nature, and connections of his cortical neurons, and the number and nature of the receptor impulses transmitted over those neurons. Heredity and environment are important factors in every individual's mental make up.

At birth the new born infant is little more than a splanchnic automaton, made up of a series of hunger reflexes. With growth and medullation of neurons from neuroblasts, there follows the acquisition of the perception of certain physical properties, such as sight, hearing, smell, taste, touch, and similar senses, all of which gradually increase the range of consciousness. Simultaneously with the acquisition of these

properties, more and more visceral or entero-ceptive and proprio-ceptive impulses are added, which inform the individual of the state of his own body, and the child walks. With the acquisition of speech still more neuroblasts are converted into functional neurons, and the range of consciousness is still further increased, until gradually, and partly depending on the mode and type of education, the full complement of sensory or receptor impulses is acquired, and the infant passes from the undeveloped state of the idiot to that of the conscious, reasoning, adult—but only provided that cerebral development proceeds normally and to full maturity. As all these impulses involve neuronie arcs and pathways, and a general synchronisation in the cerebral cortex, and as all these differ materially in different individuals, it follows that no two have exactly the same mind, the same intelligence, or the same outlook on life, for no two individuals can have had precisely the same experiences (receptor impulses) or the same number of neurons for their storage (memory).

That the telencephalic neopallial cerebral hemispheres control individual behaviour, that is, the reaction to the environment, and that, consequent on their full development, behaviour ceases to be generic and becomes individualistic, is certain. Nor can there be any doubt that they do so entirely because they contain a sufficiency of neurons for the purpose. Should these be insufficient, or seriously retarded in development, arrested, say, at the stage normally attained about the eighth month of intra-uterine life, microcephalic idiocy of a gross type results. Thus a sufficient degree of cortical development is essential to give a typical human reaction to the environment.

CHAPTER XXIII.

THE NAKED EYE ANATOMY OF THE CEREBRAL HEMISPHERES

General Configuration. The cerebral hemispheres, two in number, form the largest part of the adult brain, and assume the form of two ovoid masses, separated one from the other by the medianly situated longitudinal fissure of the brain.

The *longitudinal fissure of the brain* is a deep medianly situated fissure which passes from the vertex to the base of the cerebral hemispheres, in such a way as to separate them completely from each other. This separation is complete at the frontal and occipital ends, but in the middle it is interrupted by a white commissural band, the corpus callosum. The fissure is occupied by a median fold of dura mater, the falx cerebri, which partially subdivides that part of the cranial cavity which lodges the cerebral hemisphere into a right and left half.

Each cerebral hemisphere presents for examination three surfaces, three borders, and three poles. The three *surfaces* are the convex or lateral, the medial, and the basal. The three *borders* are the superomedial, inferolateral including the superciliary, and the interrupted medial orbital and medial occipital. The three *poles* are the projecting ends of the cerebral hemispheres and are, respectively, frontal, temporal and occipital.

Morphological Subdivision of the Human Telencephalon. In man the telencephalon attains its highest development and consists, morphologically, of three unequal parts, the striate body, the archipallium or olfactory brain, and the neopallium, the last being the most important of the three, and attaining its highest development in man. This development of the neopallial portion of the telencephalon has, in man, proceeded

to such an extent, as to overshadow the more primitive archipallium or olfactory brain thereby making the recognition of the parts of the latter rather difficult in the human brain, though in many of the lower mammals, such as the sheep, rabbit, dog, and horse, the distinction between archipallium and neopallium is obvious. In the human being the olfactory brain has been largely superseded by the neopallial brain of reason and control, and hence it has long been the anatomical custom to divide the human brain into two parts—neopallium and archipallium—and to subdivide the former into lobes by means of sulci. As this anatomical subdivision of the human neopallium into lobes is now known to have no morphological or functional significance the account which is to follow will be considerably curtailed.

The Neopallium. The neopallial or non-olfactory portion of the human telencephalon forms the main mass of the cerebral hemispheres, and is markedly fissured on the surface—an arrangement which increases the number of cell-bodies in the cerebral cortex. These fissures are termed *sulci*, and the intermediate portions, *gyri*. Since the external grey or cortical substance of the brain is continuous over the whole surface of the cerebral hemispheres, being found both within the sulci and upon the gyri, it is obvious that a far greater extent of grey matter is thus provided with a given size of brain, than would be the case had the human cerebral hemispheres been plain and destitute of convolutions. In fact, the sunken or concealed surface of cerebral cortex is about double that of the exposed surface, and the human brain is thus gyrencephalic. The convolutions themselves present considerable variations of position, direction, and complexity in the brains of different individuals, and even in the two sides of the same brain, but they are usually easily recognisable, and conform generally to type.

The *sulci* of the human brain belong to one or other of four great groups. There are, first, the *terminal sulci* to which belong the majority of the cerebral sulci; these are placed between cortical areas of different function, as, for example,

the central sulcus, which separates the motor or effector precentral cortex, from the sensory or receptor postcentral cortex. Second, there are the *axial sulci*, which result from the infolding of areas of the same function and uniform structure, as, for example, the lateral occipital sulcus in the cortical area of vision. Third, are the *opercular sulci*, where the edge of one

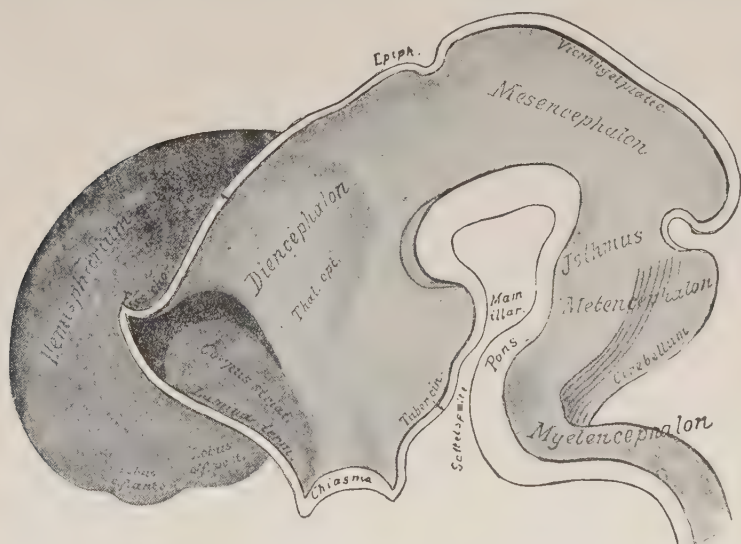


FIG. 95.—Median section through brain of a human embryo in fifth week. (His.) (From: Luciani, "Human Physiology.")

cortical functional area becomes pushed over another, as, for example, the lunate sulcus. Lastly, there is a group of *cerebral sulci*, the formation of which is determined by mechanical or developmental factors, and of which the parieto-occipital sulcus and the lateral fissure of Sylvius are examples.

The *gyri* or *convolutions* are those portions of the cerebral cortex found between, or in the depths of, the sulci. Those visible on the surface usually assume the form of longer or shorter, and more or less curved, elevations, separated from each other by the sulci. In addition to the gyri seen on the surface, there are, however, certain others concealed in the depths of the sulci, and termed *deep gyri*. Those gyri situated

either on the surface or within the depths of a sulcus which connect two longer gyri are termed *transitional gyri*.

The Lateral Surface of the Cerebral Hemisphere. The lateral, or dorsolateral, surface of each cerebral hemisphere is convex and is accurately adapted to the deep surface of the cranial vault. Upon this surface there are to be recognised three main sulci, the lateral fissure of Sylvius, the central

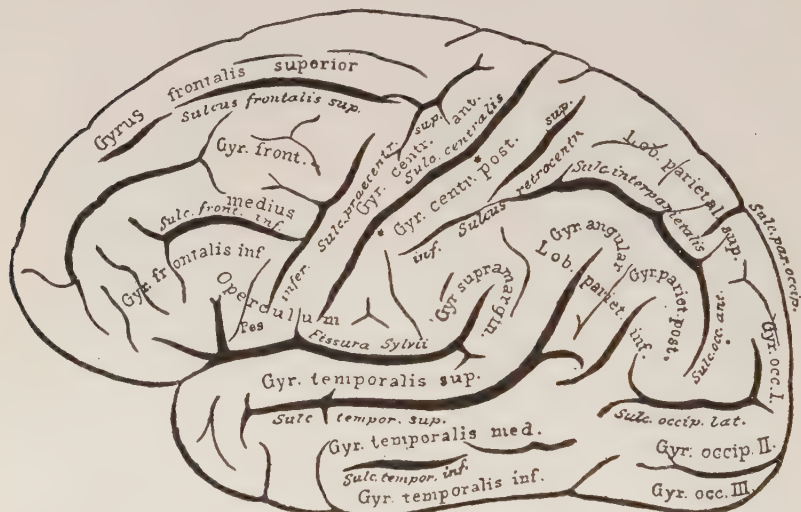


FIG. 96.—External aspect of left cerebral hemisphere. The names of the gyri and lobules are marked in Roman type; those of the sulci and fissures in italics. (From: Luciani, "Human Physiology.")

sulcus of Rolando, and the parieto-occipital notch; the frontal, parietal, occipital, and temporal lobes, as well as the concealed insula; and the secondary sulci associated with these anatomical lobes.

The *lateral fissure of Sylvius* is the most conspicuous sulcus of the adult brain. It consists of a short main stem, situated upon the base of the brain, from the lateral end of which three branches radiate out upon the lateral surface of the brain. The *stem* of the fissure lies on the base of the brain, where it commences at the anterior perforated substance in a deep depression, termed the *vallecula Sylvii*. From this point the

stem passes horizontally laterally, in the form of a deep cleft intervening between the temporal pole and the orbital area of the base of the brain, and thus makes its way to the lateral surface of the brain, where it terminates at the *Sylvian point*, by breaking up into the anterior horizontal limb, and the more important posterior limb. The *anterior horizontal limb* extends from the Sylvian point horizontally into the frontal lobe for about 2cm., parallel with the superciliary border. The *anterior ascending limb* extends from the Sylvian point into the frontal lobe for about 2.5cm. The important *posterior limb* of the lateral fissure of Sylvius extends from the Sylvian point occipitally, with a slightly upward tendency, for about 5 to 7 cm. At first it lies between the frontal and parietal lobes, on the one hand, and the temporal lobe on the other, and thereafter terminates, in the form of an ascending terminal piece, in the parietal lobe.

The *central sulcus of Rolando* is a terminal sulcus, which courses obliquely across the central part of the lateral cerebral surface. It intervenes between the frontal and parietal lobes, and between the motor or effector cortex and the sensory or receptor cortex. The sulcus commences at the *superior Rolandic point* on the supero-medial border of the hemisphere, a short distance on the occipital side of the mid-point between the frontal and occipital poles, and it is not infrequent for this end to turn round the supero-medial border for a short distance on to the medial surface. From the superior Rolandic point the central sulcus passes obliquely across the lateral surface of the brain, to terminate just above the middle of the posterior limb of the lateral fissure of Sylvius, at the *inferior Rolandic point*. The central sulcus is not straight, but is distinctly sinuous, the bends which it forms being known as the *superior* and *inferior genu* respectively. These genua indicate the upper and lower levels of that portion of the Rolandic "motor" area, on the frontal side of the sulcus, which is known as the "arm" centre. The general angle which the central sulcus makes with the longitudinal fissure of the brain is termed the *Rolandic angle*. It is open frontally, and averages

71.7 degrees, but varies from 69 to 74 degrees. If the central sulcus be widely opened, a deep annectant gyrus may often be seen extending across its depth, the presence of which is due to the fact that the central sulcus is, developmentally, laid down in two parts, an inferior part covering the lower two-thirds of the adult sulcus, and appearing at an early stage of development, and an upper part, appearing at a later period, covering the upper third. With subsequent development the annectant gyrus should become submerged in the sulcus. Should it not do so, that very rare abnormality—division of the central sulcus into two parts—results.

The *parieto-occipital fissure* is really a fissure of the medial surface, but it usually notches the supero-medial border and part of it can thus be seen on the lateral surface as the *parieto-occipital notch*, and is there used as the dividing spot between the parietal and occipital lobes.

The *frontal lobe* occupies all that portion of the lateral surface of the brain which lies in front of the central sulcus of Rolando. Within it may be identified three chief, but variable, sulci. Of these the *precentral sulcus* is more or less parallel with the central sulcus, and is often divided into two parts, upper and lower. The *superior frontal sulcus* usually begins in the precentral sulcus and runs towards the frontal pole parallel with the supero-medial border of the brain. The *inferior frontal sulcus* similarly usually begins in the inferior precentral sulcus and runs towards the frontal pole more or less parallel with the preceding sulcus. By means of these three sulci the frontal lobe may be divided into one vertical and three horizontal convolutions, named, respectively, the precentral or anterior central gyrus, superior, middle, and inferior frontal gyri. Of these the *precentral gyrus* lies between the central and precentral sulci, and comprises the motor or effector cortex. The *superior frontal gyrus* lies between the upper margin of the hemisphere and the superior frontal sulcus; the *middle frontal gyrus* between the superior and inferior frontal sulci, and the *inferior frontal gyrus* lies between the inferior frontal sulcus and the superciliary border

of the brain. This last convolution is cut into by two of the limbs of the lateral fissure of Sylvius and is thus subdivided into an *orbital part* below the anterior horizontal limb of the lateral fissure of Sylvius; a *triangular part* between the two anterior limbs of the same fissure; and an *opercular part* between the anterior ascending limb of the lateral fissure of Sylvius and the inferior precentral sulcus. Damage to, or disease of, the occipital end of the middle frontal convolution is found to abolish or impair the power of writing, whilst similar pathological or embryological alterations in the occipital end of the inferior frontal convolution cause a loss, or impairment, or articulate speech. Those portions of the superior, middle, and inferior frontal convolutions which are not specially concerned in the performance of some particular function constitute the *frontal association area* of Flechsig. It is thus clear that the old anatomical subdivision of the frontal lobe has no association with function whatsoever, and is thus largely obsolete.

The *temporal lobe* comprises, roughly, all that portion of the lateral surface of the brain which lies below the lateral fissure of Sylvius and takes in the temporal pole. Portion of this area is specially concerned in hearing. In *frontal section* the temporal lobe is three-sided, but of its three sides, one, the superior or opercular surface is concealed within the lateral fissure of Sylvius, whilst the remaining two surfaces are visible on the lateral and basal surfaces of the hemisphere itself. The *upper* or *opercular surface* of the temporal lobe is concealed within the lateral fissure of Sylvius, which must be widely opened to expose it. Near its occipital end it is marked by some horizontal convolutions, termed the *transverse temporal gyri*. One of these, better marked than the others, forms the *anterior transverse temporal gyrus* or *Heschl's convolution*, and represents the cortical centre for hearing. The *lateral surface* of the temporal lobe presents two well marked sulci, and a variable third, named, respectively, the superior, middle, and inferior temporal sulci. The *superior temporal sulcus* is a very constant and well-marked sulcus which lies below,

and parallel with the lateral fissure of Sylvius, and cuts upwards, at its occipital end, into the parietal lobe. The *middle temporal sulcus* lies below and parallel with the former, and usually appears in two disconnected parts. The *inferior temporal sulcus* is very variably developed and most frequently lies on the basal surface of the brain. Above each one of these sulci is a convolution similarly named, and there are thus *superior, middle, and inferior temporal convolutions*.

The *parietal lobe* is that part between the central sulcus and the parieto-occipital notch and above the posterior horizontal limb of the fissure of Sylvius. Within this area are certain sulci, such as the composite interparietal, as well as the upturned ends of the lateral fissure of Sylvius and the superior temporal sulcus. The *interparietal sulcus* is a composite sulcus built up of four developmentally separate parts, two of which run vertically, and two horizontally. The former comprise the superior and inferior postcentral sulci, and the latter the interparietal or horizontal sulcus and the transverse occipital sulcus. Very great variation is shown in the subsequent development and mode of union of these four originally separate parts of the composite interparietal sulcus. The *postcentral sulcus* runs behind, and parallel with, the central sulcus of Rolando and consists of two parts, upper and lower, which may, or may not, unite with each other or with the horizontal portion of the interparietal sulcus. There is a strong analogy between the postcentral sulci, the central sulcus, and the precentral sulci, all of which form a group of radial sulci on the lateral surface of the foetal brain above the Sylvian region, and each of which is laid down in two parts, upper and lower. The *central sulcus* appears first, and its two parts unite early. The *precentral sulcus* appears second, and its two parts usually remain separate, whilst the *postcentral sulcus* is the last of the three to appear, and its two parts usually unite, but fail to do so in about 20% of cases.

The composite interparietal sulcus divides the lateral surface of the parietal lobe into three unequal anatomical areas; of these the *posterior central gyrus* lies between the central

and postcentral sulci; the *superior parietal lobule* lies above the horizontal portion of the interparietal sulcus, and the *inferior parietal lobule* below it. Cutting into the latter are the upturned ends of the posterior horizontal limb of the lateral fissure of Sylvius and the superior temporal sulcus. Around the former is the *supramarginal gyrus*, and around the latter is the *angular gyrus*.

The *occipital lobe* occupies but a small portion of the lateral surface of the cerebral hemisphere, and comprises that part which lies behind the parietal notch. The visual area of the cortex, which occupies the medial surface of the occipital area, is sometimes prolonged over the occipital pole on to the lateral surface, in which case its lateral limits are usually circumscribed by a small semilunar furrow termed the *lunate sulcus*.

The *insula* or *island of Reil* differs from all the other anatomical cerebral lobes inasmuch as it is a concealed lobe, and is not visible on any surface of the brain without dissection. To expose it, the lateral fissure of Sylvius must be widely opened up, or those portions of the cerebral hemisphere—the opercula—which overlies it, must be cut away. The insula is that part of the telencephalic wall which overlies the striate body and lags behind in its development, and so becomes overgrown by the surrounding neopallium. It is circumscribed by the *circular sulcus*, and its surface is crossed by the *central sulcus of the insula*, which, developmentally, is part of the central sulcus of Rolando. As the adjacent portions of the neopallium gradually grow over the insula, they form, by their approximation, the posterior horizontal limb of the lateral fissure of Sylvius, and these parts are termed the *opercula*, of which there may be recognised frontal, temporal, and parietal.

The Medial and Basal Surfaces of the Cerebral Hemispheres. After removal of the cerebral hemispheres from the skull, if the corpus callosum be divided in the middle line, a good view will be obtained of the medial and basal surfaces of each hemisphere, and on these combined surfaces, the old

anatomical subdivision into lobes is even more obsolete, than on the lateral surface. At the occipital end there are to be recognised the parieto-occipital and collateral fissures.

The *parieto-occipital fissure* is a deep fissure or fossa found on the medial surface of the hemisphere, which extends from the supero-medial border to a point a short distance dorsal to the splenium of the corpus callosum, where it terminates by cutting into the calcarine fissure. It separates the pre-

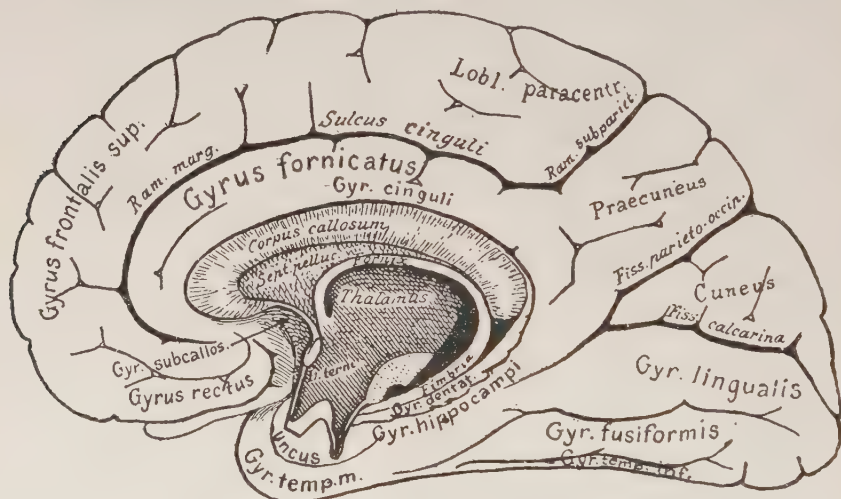


FIG. 97.—Median longitudinal section through adult brain. The posterior parts of the thalamus, cerebral peduncles, etc., have been removed, so as to expose the inner surface of the temporal lobe. (From: Luciani, "Human Physiology.")

cuneus from the cuneus, and contains much cortex within its depths. The upper end of this fissure extends on to the lateral surface of the brain and there forms the parieto-occipital notch.

The *collateral fissure* occupies the tentorial portion of the basal surface. It extends from the occipital pole towards the temporal pole, and is sometimes continuous with the *rhinal fissure*. The collateral fissure separates, in order from the occipital to the temporal pole, the lingual gyrus above it, from the fusiform gyrus below it, and the hippocampal gyrus above it from the temporal continuation of the fusiform gyrus

below it. The *rhinal fissure* is well marked in most mammalian brains, where it forms the natural line of demarcation between the olfactory archipallium and the neopallium. In man it is only occasionally present as a distinct fissure, but when present, it can be seen to separate the terminal part of the hippocampal gyrus (archipallium) from the rest of the temporal lobe (neopallium).

All that area which lies between the parieto-occipital and collateral fissures comprises the visual occipital cortex, and is thus of more than ordinary importance. This cortical area is infolded, and this infolding produces the *calcarine sulcus*. This sulcus commences at the occipital pole and passes thence frontally. Having been joined by the parieto-occipital fissure, it terminates below the splenium of the corpus callosum. The parieto-occipital and calcarine fissures thus form a Y-shaped figure. Between the two diverging limbs of the Y is that wedge-shaped portion of the occipital visual area termed the *cuneus*, and below the posterior part of the calcarine fissure, between it and the posterior part of the collateral fissure, is the *lingual gyrus*.

All that area of the medial and basal surfaces which lies frontal to the parieto-occipital fissure and around the corpus callosum, including the orbital area of the basal surface is unequally divided between the parietal and frontal lobes of the lateral surface. This area will be delimited by the parieto-occipital fissure, the hippocampal fissure, and the basal stem of the lateral fissure of Sylvius, and, with the exception of the precuneus between the parieto-occipital fissure and the upturned end of the calloso-marginal sulcus (*sulcus cinguli*), which belongs to the parietal lobe, it all forms part of the frontal lobe. That this area has not so previously been described has been due to a misconception as to the extent of the olfactory brain, which is much more circumscribed than hitherto thought.

On the medial surface of the frontal lobe, as thus described, there is one large sulcus, the *calloso-marginal* or *sulcus cinguli*. This commences below the rostrum of the corpus callosum,

and, sweeping round the corpus callosum, about midway between it and the upper border of the hemisphere, turns upwards to terminate just behind the upper end of the central sulcus of Rolando. This upturned end of the sulcus is sometimes specially named the *marginal sulcus*, and forms the line of division, on this surface, between the parietal and frontal lobes. The area between the calloso-marginal sulcus and the corpus callosum is the *gyrus cinguli*, previously described as though it were a part of the olfactory archipallium, which it is not.

On the *orbital* portion of the basal surface is another part of the frontal lobe, marked by some unimportant olfactory and orbital sulci and gyri.

Surrounding the corpus callosum is a deep, shallow, sulcus—the *sulcus of the corpus callosum*—which becomes continuous in the vicinity of the splenium, which the deep *hippocampal sulcus*. The latter passes forwards and terminates in the bend between the hippocampal gyrus and the uncus. The gyrus hippocampi and uncus belong to the olfactory archipallium, whilst all the rest is neopallium.

The Medial Surface of the Cerebral Hemisphere. The medial surface of each cerebral hemisphere is an approximately flat surface, which is partly free within the longitudinal fissure of the brain, and partly belongs to the third ventricle. As the majority of the sulci and gyri visible on this surface have already been mentioned, it is only necessary to recapitulate some of the more important features.

The chief sulci and fissures to be recognised on this surface of the brain are the sulcus cinguli (calloso-marginal); the parieto-occipital fissure, which separates the precuneus from the cuneus; the calcarine fissure, which separates the cuneus from the lingual gyrus; the unimportant subparietal sulcus, which separates the precuneus from the gyrus cinguli, and the so-called hippocampal fissure, which is a continuation into the hippocampal region of the sulcus of the corpus callosum, and cuts in between the gyrus hippocampi and the uncus.

The gyrus cinguli, gyrus hippocampi, and uncus are some-

times grouped together under the term *gyrus fornicatus*. Such a grouping is, however, arbitrary and misleading, as it is not in accordance with either morphological or functional fact.

In the centre of this surface of the brain there may be seen, after removal of the brain stem, the prominent corpus callosum, the septum pellucidum, the body of the fornix in part, the free part of the column of the fornix, the anterior commissure cut across in section, the interventricular foramen of Monro, the medial surface of the thalamus bounding the third ventricle and the intermediate mass. Lastly, if the hippocampal fissure be widely opened up, there will be brought into view the dentate fascia, the fimbria hippocampi and the white reticular substance of the hippocampal gyrus.

The Basal Surface of the Cerebral Hemisphere. The base of the brain constitutes the inferior aspect and is ovoid in shape. It is uneven and irregular, being accurately adapted to the floor of the cranial cavity. The several parts visible are the orbital surfaces of the frontal lobes, with the frontal poles and the olfactory lobes; portions of the temporal lobes and the temporal poles; the anterior perforated substance at the lateral angle of the optic nerves and tract; the interpeduncular fossa, bounded by the optic chiasma, optic tracts, and the peduncles of the brain; the peduncles of the brain themselves; the pons; the medulla; the cerebellar hemispheres, and the twelve pairs of cerebral nerves. All the foregoing parts are visible on the basal surface after removal of the brain from the skull cavity, and it is clear that what is then seen comprises more than the basal surfaces of the cerebral hemispheres alone.

As regards the basal surfaces of the cerebral hemispheres, after removal of all those parts which do not belong to the hemispheres, they may be said to consist of two parts. First, the basal surface of the temporal lobe, with some unimportant sulci and gyri, which rests upon the tentorium cerebelli and the floor of the middle cerebral fossa, and second, the orbital surface of the frontal lobe resting upon the floor of the anterior cerebral fossa. Upon this surface may be seen the *olfactory*

sulcus, which lodges the olfactory bulb and tract, and to the lateral side thereof are the irregular *orbital sulci* and *gyri*.

The *anterior perforated substance* lies on each side, at the lateral angle of junction of the optic nerve and the optic tract. It belongs to the posterior part of the rhinencephalon,

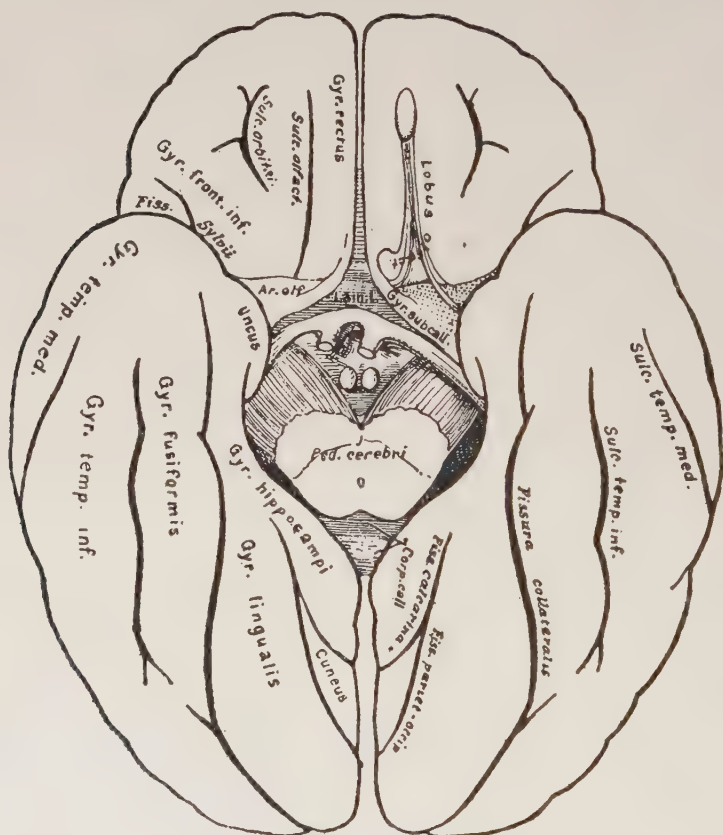


FIG. 98.—Gyri at the base of the brain. Diagrammatic. The chiasma is turned backwards. (From: Luciani, "Human Physiology.")

and is pierced by numerous holes for the passage, to the interior of the brain, of small blood vessels.

The *interpeduncular fossa* is the deep, irregular recess situated in the median plane, and bounded by the optic chiasma, optic tracts, peduncles of the brain, and pons. From this space

there extends dorsally along the upper border of the pons a recess, the *posterior recess*, whilst a similar space between the mammillary bodies is termed the *anterior recess*. The floor of the interpeduncular fossa is formed by the posterior perforated substance, the corpora mamillaria, and the tuber cinereum. Projecting from the centre of the tuber cinereum is the infundibulum, which, in the living subject, is connected with the hypophysis, but is usually divided in the removal of the brain.

The *posterior perforated substance* consists of grey cerebral substance perforated by numerous holes for the transmission of branches of the posterior artery of the brain.

The *mammillary bodies* are the two small, white eminences which lie side by side on the frontal side of the posterior perforated substance. They are associated with the fornix.

The *tuber cinereum* is the raised area of grey matter which lies, in the median plane, between the optic chiasma and the corpora mamillaria. Arising from this, on the immediate occipital side of the optic chiasma, is the *infundibulum*, or hollow stalk, which connects the base of the brain with the hypophysis. A probe passed through the infundibulum towards the brain enters the third ventricle.

The Human Neopallium. It is thus clear that almost the entire surface of the human cerebral hemisphere is formed by the neopallium. The uncus and adjacent part of the hippocampal gyrus alone belong to the archipallium. The other superficial parts of the human rhinencephalon are the olfactory bulb, tract, and triangle, as well as the cortex of the anterior perforated substance.

CHAPTER XXIV

THE RHINENCEPHALON

Definition. By the rhinencephalon is meant the olfactory portion of the cerebral hemisphere, and designated *archipallium*, in contradistinction to the more recently added non-olfactory brain, or *neopallium*.

Evolution. Phylogenetically very old, the rhinencephalon varies very greatly in relative importance in the different classes of vertebrates. The central connections of the olfactory nerves form all, or almost all, of the cerebral hemispheres of the selachian brain, whereas, in the mammal, the more recently evolved neopallium, or non-olfactory brain, becomes the dominant part. Even among the mammals there is great variation in the importance and relative size of the olfactory apparatus. The rodents, for example, depend to a great extent on the sense of smell in their search for food, and possess a highly developed rhinencephalon. Such mammals, with a highly developed sense of smell, are termed *macrosmatic*, whilst man, on the other hand, is *microsmatic*. In man the sense of smell has almost disappeared, and consequently the central connections of the olfactory neurons are of little importance. Further, it is obviously impossible for man to visualise how the universe appears to an animal with a magnified sense of smell, though he can study the reactions of the animal to the environment, and thoroughly establish the vast importance to the animal of this magnified sense. Carnivora and ruminants are in an intermediate group between the rodents and man. (Ranson.)

In man, consequent on the enormous expansion of the neopallium, or non-olfactory cerebral cortex, with its association areas, the sense of smell has been largely suppressed, and has

become of very little importance either in the human economy or from the standpoint of disease. This being so it will suffice to set forth the main structural parts of the system in the human brain, whilst the unimportant central connections may be largely omitted.

Anatomical Parts of the Human Rhinencephalon. Consequent on the overshadowing of the human archipallium by

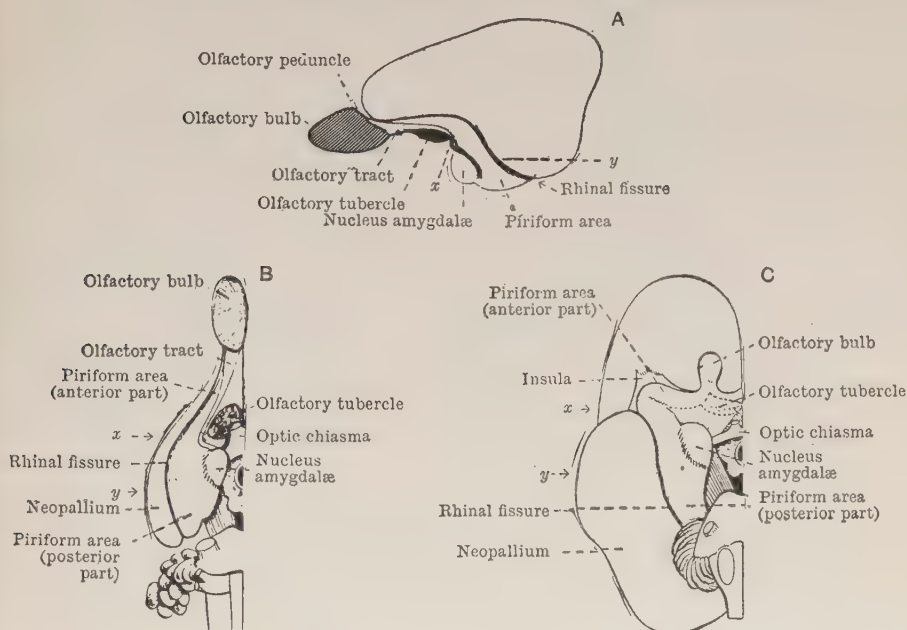


FIG. 99.—A, The lateral aspect of the left cerebral hemisphere of a rabbit. B, The inferior aspect of the right half of a rabbit's brain. C, The corresponding view of a human foetal brain at the fifth month. (From: Cunningham, "Textbook of Anatomy.")

the neopallium in the adult brain, the constituent anatomical elements of the human rhinencephalon are not well seen, but are best studied in the brain of a five months human foetus, or the brain of a sheep.

The *olfactory nerves*, from the olfactory mucous membrane, terminate in the *olfactory bulb*—an originally hollow structure which becomes solid in the adult. The connection between olfactory bulb and cerebral hemisphere becomes

drawn out into the *olfactory tract*, which, at its cerebral end, appears to divide into medial and lateral olfactory striæ or gyri.

The *medial olfactory stria* or *gyrus* is not very definitely known, but it would appear as though it established

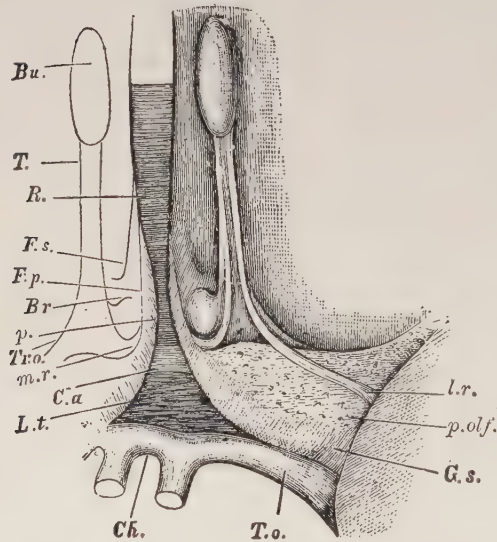


FIG. 100.—Olfactory lobe of human brain. (His.) Bu., olfactory bulb; T., tract; Tr.o., trigone; R., rostrum of corpus callosum; p., peduncle of corpus callosum; passing into G.s., gyrus subcallosus (diagonal tract, Broca); Br., Broca's area; F.p., fissura prima; F.s., fissura serotina; C.a., position of anterior commissure; L.t., lamina terminalis; Ch., optic chiasma; T.o., optic tract; p.olf., posterior olfactory lobe (or anterior perforated space); m.r., mesial root; l.r., lateral root of tract. (From: Luciani, "Human Physiology.")

contact or continuity with certain aborted structures in the vicinity of the rostral end of the corpus callosum. In any case these structural connections are better marked in some of the lower animals than in man, and this again demonstrates the association of structure with function, and the relative unimportance of the olfactory apparatus in the human being.

The *lateral olfactory stria* or *gyrus*, on the other hand, establishes definite connections with the hippocampal gyrus,

and the two together form the *pyriform area* or *lobe*. In the human adult brain this pyriform lobe is represented by the lateral olfactory stria, the cortex subjacent thereto, the limen insulæ, the uncus, and some part of the hippocampal gyrus, but how much of the last mentioned is not yet definitely determined.

The *hippocampus* is an olfactory cerebral area and assumes

the form of a long curved elevation projecting into the cavity of the temporal horn of the lateral ventricle. It is a highly specialised cortical area which has become rolled into the ventricle along the line of the hippocampal fissure. It is covered on its ventricular surface by a thin coating of white matter, termed the *alveus*, which is continuous along its medial edge with a band of white fibres, the *fimbria*, continuous with the fornix. Along the inner or medial border of the fimbria is a narrow serrated portion of grey matter, termed the *dentate fascia*. The hippocampus and the dentate fascia both belong to the archipallium, and those portions of these structures above the level of the corpus callosum seem, in the human brain, to have become atrophied and are known as the *hippocampal rudiment*.

The *hippocampal rudiment* is a thin sheet of grey matter on the upper or dorsal surface of the corpus callosum, which is so thin as to be translucent, and through it can be seen the medial and lateral longitudinal striæ of the corpus callosum. This rudimentary hippocampal formation represents an atrophied portion of the olfactory brain of man, and can be traced right round the corpus callosum from the medial olfactory stria or gyrus, at the rostral end, to the splenial end, where it becomes continuous with the hippocampus proper, which is still functional in the human brain.

General Course of Olfactory Neurons. Whilst the central connections of olfactory neurons are not, in the human being, of sufficient importance to warrant any detailed study, apart from their purely neurological aspect, it may be generally stated that *receptor* neurons pass from the olfactory bulb, through the lateral olfactory stria, to the pyriform area, whence they are conveyed to the hippocampus and dentate fascia. *Effector* neurons have their pyramidal cell bodies in the hippocampus, and pass through the fimbria and fornix as both commissural and projection fibres of the olfactory system. The *commissural olfactory neurons* run through the hippocampal commissure, as the transverse fibres of the psalterium, and serve to unite the two hippocampi. The

projection olfactory neurons pass through the fornix, which is thus the great effector projection tract of the archipallium and serves to convey impulses from the hippocampus to the hypothalamus and reticular formation of the brain stem. Through the mammillary bodies olfactory impulses are relayed along the mammillo-thalamic tract to the thalamus, and along the mammillo-tegmental bundles to the tegmentum of the pons and medulla.

The *anterior commissures* contain fibres joining together the two olfactory bulbs and also fibres linking together the pyriform areas. In the human brain the anterior commissure is mostly made up of the latter.

CHAPTER XXV

THE CEREBRAL CORTEX

Naked Eye Sections Through the Cerebral Hemispheres. Sections cut in any direction through the cerebral hemispheres show that they are everywhere composed of two parts, the external grey cerebral cortex, and the internal white medullary core or centre.

The *grey cerebral cortex* forms a convoluted lamina spread out over the entire surface of the cerebral hemisphere. It is composed of neurons exclusively confined to the grey matter, of the cell bodies of neurons the axons of which pass out of the cerebral cortex, and of medullated axons which enter the cerebral cortex from the white medullary centre.

The *white medullary centre*, on the other hand, is exclusively composed of medullated axons and contains no cell bodies whatsoever. In both cortex and medullary centre the nerve elements are supported in a neurological framework which is entirely non-nervous in structure and function.

Stratification of the Cerebral Cortex. If sections be cut through the cerebral cortex in the fresh brain, there can be seen with very low magnification, or even in some parts with the naked eye, white lines running in the cerebral cortex parallel with the surface. These white lines alternate with darker streaks, and thus the cerebral cortex appears to be laminated. The white lines are in part composed of the medullated axons of neurons which have entered the cerebral cortex in order to discharge their nerve impulses. The darker lines are the places where the cell bodies of the cortical neurons predominate. In this way there is produced an appearance of alternating whitish and greyish streaks or strata within the cerebral cortex, and it is now known that this stratifica-

tion of the cortex possesses much functional significance, and it is also known that the precise mode of arrangement of these white and grey strata differs in different parts of the cortex in accordance with the particular function to be fulfilled. Elliot Smith, by an examination and measure-

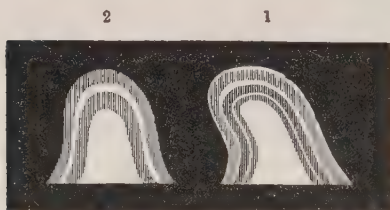


FIG. 101.—Sections of cerebral convolutions. (Baillarger.) Approximately natural size. 1, show the six layers usually seen in the cortex with the naked eye; 2, appearance of a section of a convolution from the neighbourhood of the calcarine fissure. (From: Luciani, "Human Physiology.")

ment of the thickness of the grey cerebral cortex and the character of the white lines referred to, has been able to recognise more than thirty different types of cortex in addition to the various parts of the archipallial rhinencephalon. These different areas are known to fulfil different functions, so that the stratification of the cerebral cortex is clearly a matter of functional significance.

In most parts of the cerebral cortex two well-defined white bands or lines, composed of medullated axons, can be seen. These are known as the outer and inner *lines of Baillarger*, and contain large numbers of medullated axons running in planes parallel to the surface of the cortex. In the visual region around the calcarine fissure only the outer of these lines is visible, but it is here so very distinct that it receives a special name. It is called the *stria of Gennari*. Medullated axons enter the cerebral cortex from the white medullary centre in radial bundles that in general have a direction perpendicular to the surface, but on entering the cortex they turn parallel with the surface, at right angles to their first course, and so produce the lines referred to.

The Medullated Axons of the Cerebral Cortex. The medullated axons which enter, or leave, the cortex at the radial bundles and form the lines of Baillarger, are either corticifugal or corticipetal.

The *corticifugal axons* are those of the pyramidal and

polymorphic cells of the cortex. Having entered the medullary centre they run as *association* fibres to other parts of the cerebral cortex of the same hemisphere; as *commissural* fibres through the corpus callosum to the cerebral hemisphere of the opposite side; or as *projection* fibres to the thalamus or other parts of the neuraxis at lower levels.

The *corticopetal axons* are derived either from the thalamus or from the associational and commissural systems.

The Nerve Cells of the Cortex. The nerve cells of the cortex, that is, the cell bodies of cortical neurons, alternate with the white lines of Baillarger, and comprise two great groups, those confined to the grey cortex itself, and those whose axons leave the cortex. The *former* group comprises the stellate or granular cells (Golgi Type II), the horizontal cells of Cajal, and the cells of Martinotti. The *latter* include the numerous pyramidal and polymorphic cells—the polymorphic cells being found chiefly in the internal or deeper strata of the grey cerebral cortex, and the pyramidal in the outer or more superficial strata of the cortex, with the stellate or granular cells between the two, so that even with high magnification, the stratified structure of the grey cerebral cortex is still seen to be its most obvious and most striking characteristic.

Importance of Cortical Structure in Health and Disease. Since the publication in 1905 of Campbell's "Histological Studies on the Localisation of Cerebral Function," substantiated and elaborated by the more recent, and equally important, work of Shaw Bolton, Watson, and Mott, much can now be said with certainty as to the meaning and significance of cortical histology, and a subject, usually regarded as of no importance except to the academic investigator, is found to be of intense fascination, and to underlie almost every phenomenon of daily and social life, both in health and disease. and to afford the only sure guide to the study of mind and its aberrations.

General Principles Underlying the Construction of the Nervous System of All Vertebrates. It has long been known

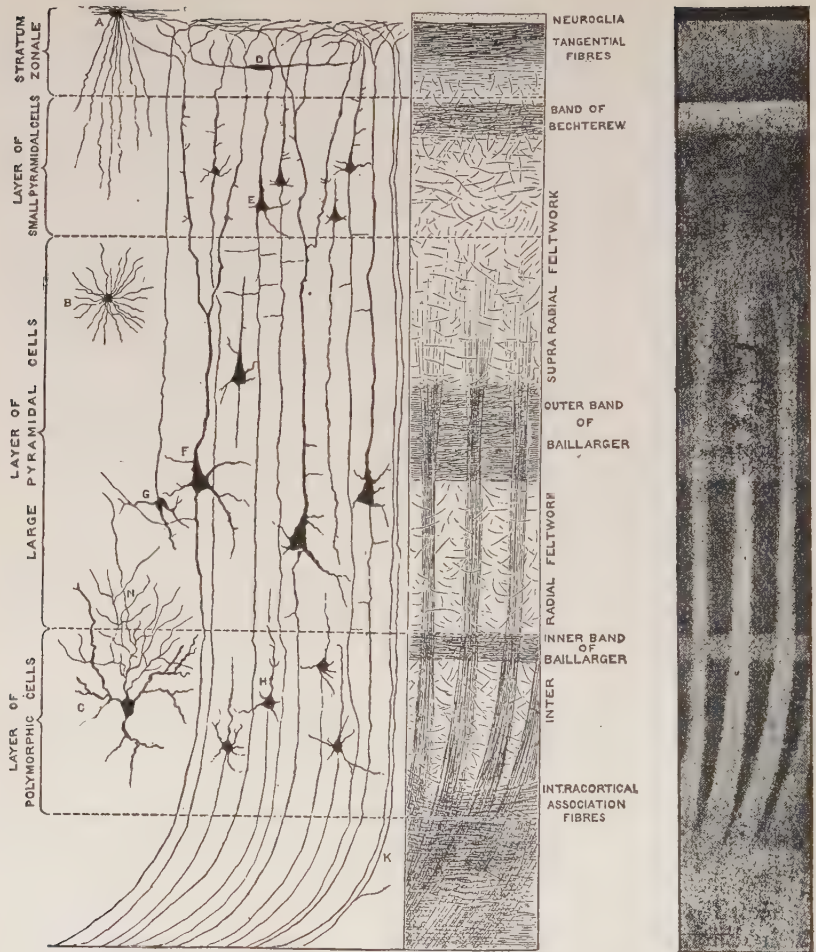


FIG. 102.—Diagram to illustrate the minute structure of the cerebral cortex and explain how it influences the macroscopic appearance. A, B, neuroglia cells; C, cell with short axon (N) which breaks up in free arborisation; D, spindle-shaped cell in stratum zonale; E, small pyramidal cell; F, large pyramidal cell; G, cell of Martinotti; H, polymorphic cell; K, corticopetal fibres. (From: Cunningham, "Textbook of Anatomy.")

that the principle underlying the structure of the nervous system of all vertebrates is a series of anatomically independent long conducting neurons, linked together physiologically into chains and neuronic arcs, by a more or less complicated series of shorter internuncial or interpolated neurons, which

form a species of junctional nerve tissue. With successive rises in the animal scale these internuncial neurons become more numerous and more complicated, culminating in the association areas of the human cerebral cortex, which, structurally, are but enormously complex equivalents of the neuropile of the earthworm. Although differing in details, all parts of the cerebral cortex exhibit an essentially similar structure and "from the physiological standpoint cortical responses are of the order of reflex actions, and must be investigated and, if possible, explained from this point of view." (Howell.)

Three Types of Internuncial Neurons. By internuncial neurons are meant those nerve elements interposed between the conducting receptor and effector neuronie limbs of the neuronie arcs, and of these every branch of study shows that in the vertebrate neuraxis there are three chief types:

The segmented spinal cord type, chiefly associational or commissural in nature, with axons passing out of the grey matter.
The supra-segmental cerebellar type, chiefly short "granular" or Golgi Type II neurons, with axons confined to the grey matter.
The supra-segmental cerebral cortical type, compounded of the first two types.

The nervous system of all animals, man included, is always and everywhere compounded of these same structural units, neurons, linked physiologically by connector or internuncial neurons and synapses, into conducting neuronie arcs. The only observable differences are in the number and nature of the internuncial neurons between the receptor and effector limbs of the arcs. If the neuraxis be *entirely segmental* in type, as in practically all animals lower than mammals, the junctional nerve tissue is of the spinal cord type, and comprises a varying number of associational and commissural neurons interposed between the longer conducting limbs of the arcs. Nerve impulses are, therefore, quickly transmitted through the whole arc, and the effector response to the receptor stimulus follows almost at once, that is, the resultant action is reflex and rapid, and physiologically, it is

always possible, in the lower animals, to forecast with precision, the nature of the response to the stimulus.

In higher animals, where cerebral additions have been made to the spinal cord, the neuraxis is partly *segmental* and partly *supra-segmental*. In the segmental portions of the neuraxis the junctional nerve tissue is exactly as it was before, but in the supra-segmental portions of the neuraxis, as, for example, the cerebellum, an altogether different type of junctional nerve tissue is found. This assumes the form of innumerable granular or Golgi Type II neurons, strictly confined to the grey matter, and interposed between the receptor and effector limbs of the neuronic arcs. Proprioceptive impulses from all sources, bones, joints, muscles, tendons, and semicircular canals, are ceaselessly being poured into the cerebellum from birth to death, during sleep and during wakefulness. The supra-segmental cerebellum differs, therefore, from the segmented spinal cord in the presence within it of many millions of short neurons confined to the grey matter, and clearly interposed between the incoming proprioceptive axons and the outgoing effector Purkinje neurons. These last are relatively few, and these facts, namely, the large number of incoming proprioceptive axons and impulses, the enormous number of internuncial neurons, variously known as basket, stellate, and granular cells, and the relatively few outgoing effector Purkinje cells, all compel the conclusion that the function of these innumerable short neurons within the supra-segmental cerebellar cortex is the arrest, accumulation, and storage within the cerebellum, of the very numerous incoming proprioceptive impulses. It is a striking and significant fact that this structural view absolutely harmonises with the clinical conception of the cerebellum as a reservoir of pent-up nerve energy. It is also to be noted that the associational and commissural types of internuncial neuron, so characteristic of the spinal cord, do not appear to be present within the cerebellum of any animal.

With the addition of a new endbrain, the neopallial cortex, with functions different from those of either spinal cord or

cerebellum, it might be thought that Nature would have evolved a new type of junctional nerve tissue, but this is not the case. The cerebral cortex simply repeats the formula and contains *both types of junctional nerve tissue, spinal cord and cerebellar*, but here the two forms of internuncial neurons are present in enormous numbers.

The *key to cortical histology* is, therefore, to be found in the fact that the human cerebral cortex is made up of receptor axons, joined up to the effector neurons, by a complex mass of internuncial neurons of the segmented and supra-segmented varieties, and interposed, like a rheostat, between the main long conducting neurons. Within the neurons of this cortical rheostat the incoming nerve impulses become arrested, stored up, dissipated, or discharged, and thus the phenomena termed "mind" are the special functions of these cortical internuncial neurons. If from developmental errors, lack of use, or other cause, these cortical internuncial neurons do not continue their development, as they should do, from the embryonic neuroblastic condition to that of the mature neuron, there will be a corresponding diminution in the display of those effector activities termed "mind." Or, if, after a correct development from neuroblast to neuron, the latter become subsequently impaired by disease, toxæmic or other poison, or injury, there will be a proportionate diminution or even loss of mental function. When the reduction in the cortical neurons, from either set of causes, passes beyond a certain stage, the reactions to the environment will depart so markedly from the normal as to constitute insanity. The minor degrees of mental aberration usually remain unrecognised. It is thus obvious that, interpreted in terms of neuronic arcs and internuncial neurons, cerebral cortical histology, instead of being a repellant subject, becomes both intelligible and highly instructive.

Structural Elements of the Cerebral Cortex. There will thus be found within the cerebral cortex receptor axons the cell stations of which occupy other and lower levels; associational and commissural neurons of the internuncial type, the axons

of which pass out of the cortex into the white medullary centre, but have their cell stations within the cerebral cortex; the cell bodies of neurons whose axons pass out of the cortex to other parts, such as the thalamus, spinal cord, cerebellum, and possibly also to the sense organs as corticifugal fibres; whilst lastly there are in the cerebral cortex a very large number of internuncial neurons whose processes do not pass out of the cortex, but are entirely confined thereto. These constitute *internuncial neurons of the supra-segmental cerebellar type*. As will be seen later these cortical neuronie elements arrange themselves in the cortex in quite definite and orderly strata, the general arrangement, from the surface, being (1) medullated axons; (2) pyramidal cells; (3) granular cells; (4) medullated axons; (5) polymorphic cells.

If these several elements of the cerebral cortex be first studied from their relationship to the cortex itself, it will be found that the cortical neurons fall into two great groups:

- a. Those whose processes are strictly confined to the grey cortex itself, and are clearly internuncial in character and of the cerebellar type.
- b. Those whose processes, that is, the axons, pass beyond the confines of the grey matter into the white medullary centre. Many of these closely resemble the spinal cord type of internuncial neuron and are associational, commissural, or projection in type.

Cortical Neurons Strictly Confined to the Grey Matter.

The chief cortical neurons whose processes do not leave the grey cerebral cortex, include the granular, or stellate cells of the Golgi Type II variety; the cells of Martinotti; the horizontal cells of Cajal, and possibly a few others not as yet clearly known. All of these neurons are to be regarded as special forms of internuncial neurons interposed between the limbs of longer neurons, which may be associational, commissural, receptor, or effector in type. They appear to function here, as they do in the cerebellum, as storehouses of nerve impulses and distributors of the same under suitable stimulation. They are, therefore, an integral part of the actual physical mechanism of memory, speech, and consciousness, and

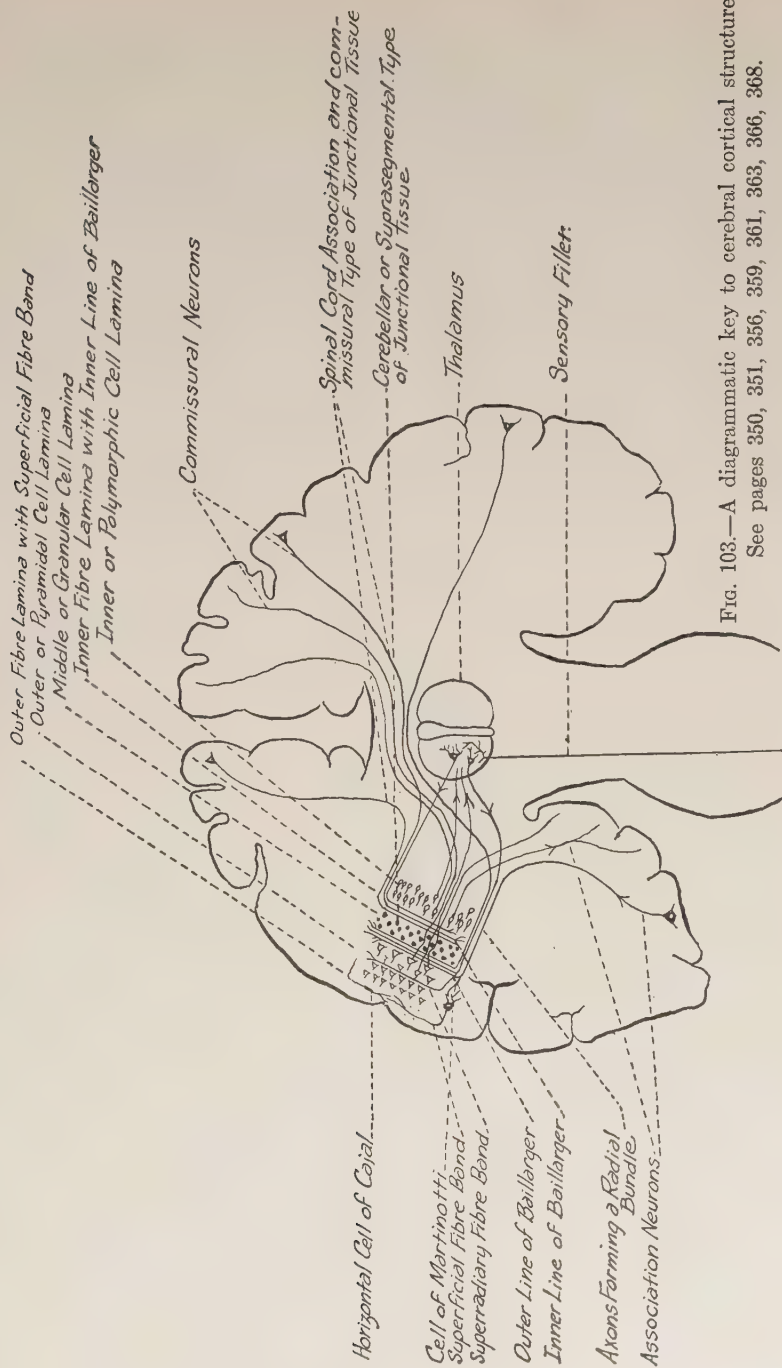


FIG. 103.—A diagrammatic key to cerebral cortical structure. See pages 350, 351, 356, 359, 361, 363, 366, 368.

the brain of man is characterised by an infinitely greater number of such neurons than is that of any other animal.

The *granular, stellate* or *Golgi Type II neuron* is present in extraordinarily large numbers in the human cerebral cortex, especially so in all the known receptor areas. These cells occupy a middle position in the cortex and separate off the more superficial pyramidal cells from the more deeply lying polymorphic cells. This layer of granular cells is, indeed, so characteristic of the human cortex that it is now generally regarded as quite naturally dividing it into an outer and an inner cortex, the former, comprising the pyramidal cells, being a comparatively recent evolutionary addition to the mammalian cortex and attaining its highest development in man. The granular neurons themselves are extremely small (5 to 8 μ), but stand out plainly under low magnification as a streak of closely packed cells, whose processes, dendrons and axons, are confined to the layer of the cortex in which they occur.

The *cells of Martinotti* occur in most of the pyramidal cell layers of the cortex. Both dendrons and axons are confined to the grey cortex, and the axon is peculiar inasmuch as it turns towards the surface of the cerebrum and away from the white medullary centre, and finally ends by ramifying horizontally in the most superficial layer of the cortex. Neurons conduct nerve impulses in the direction of the axon, and these cells of Martinotti must be links in a neuron chain conducting in that direction, that is to say, they are specially modified internuncial supra-segmental neurons.

The *horizontal cells of Cajal* are found only in the superficial layer of the cerebral cortex. They are small and fusiform, and have long dendrons arborising horizontally, and very long axons which form medullated fibres within the superficial layer of the cortex. These cells are supposed by Cajal to receive impulses from the receptor axons of the cortex, either directly or indirectly through the short axons of the granular cells, and to pass them on to the dendritic processes of the pyramidal cells which ramify within the layer—many of which are associational or commissural in type and

function. These cells would thus again appear to be specially designed cortical internuncial neurons.

Cortical Neurons Passing Outside the Confines of the Grey Cortex. Cortical neurons with their cell bodies in the grey cerebral cortex, whose axons pass out of that cortex, are very numerous, and fall naturally into two great groups:

- a. Those whose axons, though leaving the grey cerebral cortex, do not pass beyond the confines of the telencephalon.
- b. Those whose axons pass out of the grey cerebral cortex into parts of the neuraxis other than the telencephalon.

The cell bodies of all these axons lie within the grey cerebral cortex and include both the pyramidal and polymorphic types of cell bodies.

The axons of those pyramidal and polymorphic cells which, though leaving the grey cerebral cortex, do not pass beyond the confines of the telencephalon, that is, the cerebral hemispheres, form the associational and commissural fibres, and link together all parts of the same and opposite cerebral hemispheres. These, therefore, must represent the enormously extended cortical equivalents of the fasciculi proprii of the spinal cord, and apparently form part of the cortical neuronc rheostat for the accumulation, storage, discharge, or dissipation of cortical neuronc impulses.

The axons of those pyramidal and polymorphic cells which pass out of the grey cerebral cortex into parts of the neuraxis other than the telencephalon, comprise the cortico-thalamic axons, the cortico-cerebellar axons, the projection fibres of the pyramidal and other effector tracts, and possibly also the corticofugal axons which are believed to pass to the retina, cochlea, and other special receptor organs.

But the cerebral cortex also contains a large number of medullated receptor axons which enter it, through the white medullary centre, from sources outside the cortex. These include all axons from the thalamus (thalamo-cortical)—the junction house of incoming receptor neurons—and from the extero-receptive organs of sight, hearing, smell, taste, etc. These axons enter the cerebral cortex in the radial bundles referred

to, and usually turn in it in such a way as to run parallel with the surface, where they form the lines of Baillarger. Within the cortex these axons terminate in two chief situations—in the vicinity of the granular cells, or in the pyramidal cells superficial to the granular cells. It is thus clear that receptor impulses from all sources, on reaching the cortex, are transferred to a very large number of cortical neurons, which they stimulate or charge. The granular, associational, and commissural neurons must, therefore, be the physical instruments of all the phenomena of mind, for if they are not for this purpose, the inexplicable problem arises for what purpose are they? It is certain that when they are embryologically imperfect, partially absent, or impaired by disease or injury, there is an immediate and correlated loss of cerebral function, that is, of mind.

CHAPTER XXVI

THE LAMINATION OF THE HUMAN CEREBRAL CORTEX AND ITS FUNCTIONAL SIGNIFICANCE

The Five Histological Layers of the Cortex. The various cell-bodies and medullated axons found in the human cerebral cortex, of which a general account was given in the previous chapter, arrange themselves in five *primary* laminæ or layers, which are, from without inwards:

1. The superficial or outer fibre lamina.
2. The outer or pyramidal cell lamina.
3. The middle or granular cell lamina.
4. The inner fibre lamina, chiefly medullated axons.
5. The inner or polymorphic cell lamina.

These five cortical layers are more or less readily identifiable in all parts of the neopallial cortex, though they differ considerably in their degree of development in different cortical areas. In the psycho-motor area, for example, the third layer is of minimal depth, whereas in the strongly receptive visuo-sensory area, the third lamina is of great depth, because it contains a very large number of the receptive granular Golgi Type II cells, and has the further appearance of being reduplicated, because the incoming receptor visual axons conveying visual impulses lie in the middle of it.

Taking the prefrontal cortex as a type, and Bolton's work as the authority, these five cortical layers may be thus briefly described:

1. The *superficial* or *outer fibre lamina*. This layer is composed of a very complex and delicate network of fine varicose fibrils, which interlace in every direction, but run mostly parallel with the surface. In the deeper parts of this lamina, just before it passes into the pyramidal or outer cell lamina,

a sufficiently distinct decrease in the complexity of the fibrillar network exists to enable the line of separation between the two laminæ to be detected even though the nerve cells of the second layer are partially absent or invisible. As regards the presence of nerve cells, the outer fibre lamina in this region (prefrontal) resembles the corresponding lamina in other regions of the cortex in possessing few and insignificant cellular elements.

2. The *outer or pyramidal cell lamina*. This layer is largely composed of small, medium, and large pyramidal cells in that order from without inwards. The bases of the pyramids are directed inwards and the apices outwards. Rela-

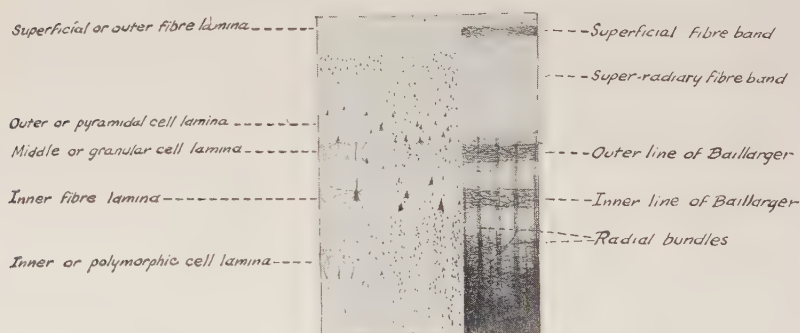


FIG. 104.—Microphotograph of the human cerebral cortex to show the layers of cells and axons. See pages 351, 358, 361, 363, 364.

tively, the brain of adult man is differentiated from that of the lower animals by the development and presence of these cortical pyramidal cells. In dementia, in which the intellectual functions have been largely lost, it is within these pyramidal cells that the most marked histological degeneration is found.

3. The *middle or granular cell lamina*. This layer is particularly well developed in all receptive areas of the cortex, and is composed of innumerable Golgi Type II neurons, confined to the layer in which they occur. The nerve cells are

small and closely packed, of irregularly shaped body, and with fine and short processes.

4. The *inner fibre lamina*. This layer is essentially a fibre layer, though it often contains large pyramidal cells.

5. The *inner* or *polymorphic cell lamina*. This lamina largely consists of polymorphic cells.

It is important to realise that these are the five *primary* laminae from which the structures of the adult human cerebral cortex are developed, and that of these, the first and the fourth, that is, the outer and inner fibre laminae, are, in essential structure, fibre *layers*, and are not to be confounded with the fibre *bands* of the adult cortex which are four in number, and from within outwards, as follows:

The inner line of Baillarger.

The outer line of Baillarger.

The super-radiary fibre band.

The superficial fibre band.

The *fourth horizontal fibre band* of the adult cortex, or the inner line of Baillarger, occupies the position of the fourth primary lamina of the cortex. It is usually a conspicuous feature of sections taken from the association areas.

The *third horizontal fibre band* of the adult cortex, or the outer line of Baillarger, thinner than the preceding, lies between the pyramidal and granular cell layers. It can be seen in sections taken from almost any part of the cortex, and is especially prominent in the visuo-sensory cortex, where it is specially named the *stria of Gennari*, and is separated off from the pyramidal cells by a second or reduplicated layer of granular cells, thus proving that its axons convey impulses to the granular cells. Further in cases of long standing or congenital blindness, the outer layer of granular cells in the visuo-sensory area is decreased in thickness by more than 10% and the stria of Gennari itself to the extent of nearly 50%.

The *second horizontal fibre band* of the adult cortex, or the super-radiary fibre band, thinner and less distinct than the two

preceding ones, can be seen in sections taken from almost any part of the cortex, though its exact position appears to differ slightly in different regions. As a general rule it lies between the smaller and medium sized pyramidal cells of the outer or pyramidal cell layer.

The *first horizontal fibre band* of the adult cortex, or the superficial fibre band lies in the outer part of the superficial or outer fibre lamina.

Correlation of the Five Histological Layers of the Cortex With the Nomenclature of Bolton and Watson. Dr. G. A. Watson also adopts the five cortical laminæ of Bolton, but employs a slightly different nomenclature. He groups the cortical layers superficial to the granular layer together as the "supra-granular" cortex, and those lying deep to the granular layer as the "infra-granular" cortex. As both methods and nomenclature are to be found in current literature it is essential to be familiar with both, which may be set forth thus:

HISTOLOGY	BOLTON	WATSON
Nerve fibrils	Outer fibre lamina	Supra-granular cortex
Pyramidal cells	Outer cell lamina	
Granular cells	Middle cell lamina	Granular cortex
Nerve axons	Inner fibre lamina	Infra-granular cortex
Polymorphic cells	Inner cell lamina	

Evolution of the Five Layered Cerebral Cortex. The mammalian cerebral neopallial cortex is built up primarily on an infra-granular basis, that is, the *infra-granular cortex* is the earliest to appear in the process of development, very quickly reaches maturity, and in the adult presents remarkably little difference in absolute thickness in either the lowest or the highest of mammals.

The *granular layer* is the next addition to the cortex and appears shortly after the infra-granular.

The last layer of the cortex to appear ontogenetically is the *supra-granular* or *pyramidal layer*. It is the slowest of all the layers to attain maturity. It is scarcely existent at all in certain regions in some, if not all, of the lowest mammals, and at its best the thickness it attains in even the higher

mammal is but slight compared with the depth of the same layer in man.

A neopallial cerebral hemisphere is a purely mammalian addition to the neuraxis, and in all the lower mammals the cerebral cortex is practically a three-layered one—an external granular layer, a deeper receptor medullated axon layer, and an internal polymorphic cell layer. In such a cortex receptor impulses conveyed by the receptor axon layer are transmitted to, or through, the granular cells, in which they may be stored up, and under some future receptor impulse, these same cells may be stimulated to discharge their stored-up nerve energy, and so give rise to a delayed, instead of an immediate, effector response. This power of delaying the response to the stimulus is the essential basis of "mind." In such a cortex provision is first made, as in the kangaroo, for the linking up of the incoming receptor impulses, as well as of the granular neurons, with all portions of the cortex of the same side, by association neurons of the polymorphic layer. As there is no corpus callosum in the kangaroo, it follows that the linking together of both cerebral hemispheres by commissural fibres is a later addition to the mammalian cerebral cortex. Mammals with a brain so constructed will, therefore, be in advance of the lower animals with no neopallial cerebral cortex, because they will be able to repeat their actions in, at least, an instinctive manner. They will not, however, be able to control or inhibit the instinctive actions, that is, if they see or smell food, they will seize it, and if the passion of desire be aroused they will seek to gratify it. In each case the appropriate effector response follows the stimulus without inhibition.

In the higher mammals there commences to be added a still more external cortical layer of pyramidal cells and the cortical neuronie pathways become considerably increased. The elements of control over actions, and the memory of previous stimuli and actions, thus begin to enter into the behaviour of the animal.

Finally, with the addition of association areas, and an enormous multiplication therein of the neuronie elements of both

infra-granular and supra-granular types, there is reached the brain of man, with its manifestations of memory, reason, speech, and thought—but—the brain is composed of exactly the same structural elements, namely, neuronics arcs with a greatly extended system of internuncial neurons. Should, therefore, the human individual be born with an insufficient number of pyramidal supra-granular neurons, it is surely futile to expect him to behave, or react to his social environment, in the way regarded as normal by the normally neuronated individual.

Functions of the Infra-Granular Cortex. By the infra-granular cortex is meant all that portion of the cerebral cortex lying internal or deep to the granular cells. The researches of Bolton on the human brain and of Watson on the mammalian brain show that the infra-granular cortex is concerned with the performance of the instinctive, in contradistinction to the reasoned and inhibitory (supra-granular), or receptive (granular) activities. It is, therefore, in the human being, the brain of those purely animal instincts which are inherent in every human individual, and are essential for the preservation of the individual and species. It is of extremely constant average adult depth, that is to say, the number of the constituent and contained cells (polymorphic) is very constant, but a very slight decrease in the depth of this layer exists in cases of high-grade amentia and of chronic insanity with moderate dementia. A considerable decrease, on the other hand, exists in more marked aments, and in gross demented who are unable to carry on the ordinary animal functions, such as attending to their own wants. In these cases the number of the constituent cells of the infra-granular cortex is clearly decreased, and the behaviour or reaction of the individual to his social environment is correspondingly altered. The main function of the infra-granular cerebral cortex is, then, to preside over those bodily actions which require, for their fulfilment, no experience or education. These actions form the basis of many complex reflexes necessary for the preservation of the individual and the species, such as the seeking appro-

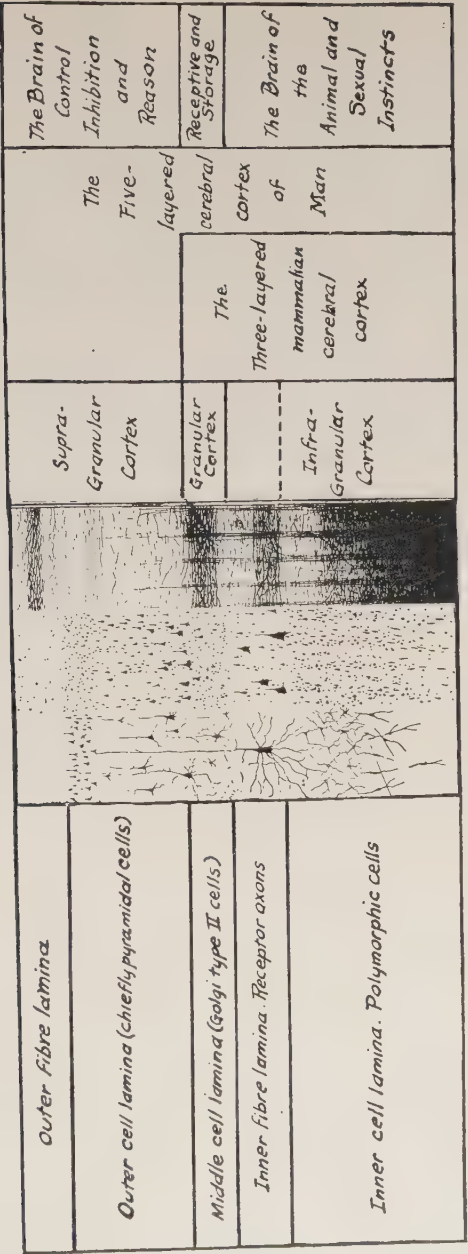


Fig. 105.—A microphotograph of the cerebral cortex to illustrate the main structural and functional differences in the brains of the mammal and man. See pages 15, 18, 364, 368, 370, 499.

priate shelter and protection, the hunting for food, and the quest of the opposite sex.

Functions of the Granular Cortex. The granular layer of the cortex is always well developed in receptor areas, and this layer thus primarily subserves the reception of impulses, whether these arrive directly from the lower receptor neurons, or indirectly from other regions of the cortex. It has already been seen that the first type of junctional nerve tissue introduced into the neuraxis is of the commissural and associational variety, as is seen in the spinal cord of almost all animals. Why then are granular neurons introduced into the supra-segmental additions? Clearly for the reception and storing of receptor impulses, and the association of present with stored impressions, and consequently the granular neurons in the human cerebral cortex must play a part in memory.

Functions of the Supra-Granular Cortex. The supra-granular cortex is a recent addition to the mammalian neopallial cerebral cortex. Watson finds that in the insectivora the pyramidal cell layer is in a rudimentary condition, but becomes better marked with each successive rise in the mammalian scale, and best marked of all in man. The supra-granular cortex is, indeed, the most prominent feature of the human brain, and constitutes a higher level basis for the carrying on of the cerebral functions. It is the last cell layer of the cortex to be evolved and the first to undergo retrogression. It is the only cell layer which varies definitely in measurable depth in normal brains. It is underdeveloped to different degrees according to the mental capacity of the individual in persons exhibiting various grades of mental sub-evolution, that is, other things being equal, such persons should have measurably smaller heads, and it undergoes degrees of retrogression which correspond to the amount of dementia existing in cases which permanently suffer from diminution or loss of their powers.

If such be the general functions of the supra-granular cortex, in what does its *histological structure* differ from that of the infra-granular? Beyond the fact that the constituent cells

of the supra-granular cortex are pyramidal in shape, instead of fusiform or spindle-shaped, and are of different size, there is apparently no difference whatsoever; in fact, the general construction appears to be a reduplication of that of the infra-granular cortex. There enter the supra-granular cortex receptor axons from the thalamus and other sources, which turn in that layer parallel with the surface, and so form another white line, in the vicinity of which are found a multitude of pyramidal cells, which are, from the surface inwards, small, medium, and large. Intermingled with these are Golgi Type II cells, horizontal cells of Cajal, and cells of Martinotti. The general construction of the supra-granular cortex is thus an almost exact repetition of that of the infra-granular cortex, but with differently shaped cells, and with different functions.

That some essential significance attaches to the fact that the infra-granular cortex is mainly composed of polymorphic cells, and the supra-granular of pyramidal, is certain, and is in accordance with the law of correlation of structure with function. In the absence of direct evidence of the meaning of these structural differences it is only possible to put forward an explanatory hypothesis from analogy.

The characteristic pyramidal nerve cells of the human cerebral cortex appear to be only variants of the Golgi Type I neuron, supposed by Golgi himself to be effector in function. All the distinctly motor or effector cells of the neuraxis are of this type. It is, of course, obvious that all the pyramidal cortical cells cannot be "motor" in the ordinary sense of the word, though it is significant that the purely "motor" cells of the cortex are of the pyramidal type, and are very large. If, however, these smaller pyramidal cells be regarded as effector or discharging cells, then the occurrence, within the cortex, of these very numerous pyramidal cells would be brought into line with known neurological facts, and there would be afforded some explanation of the occurrence of the three different sizes of small, medium, and large. The *small pyramidal cells* would form short association connections with adjacent convolutions. The *medium pyramidal cells* may not improbably

represent association connections with more distant convolutions, and the *large pyramidal cells*—the giant pyramidal cells of Betz excluded—might provisionally be regarded as the cell bodies of some, at least, of the commissural fibres passing through the corpus callosum to parts of the hemisphere of the opposite side. Although this is only hypothesis, it is, at least, in accordance with the general neurological law that the longer the axon, the larger the cell body.

On this view the function of these pyramidal cells of the supra-granular cortex would be the discharge of nerve energy in the form of mental reaction and inhibition, and we should expect to find such cells exhibiting phenomena of chromatolysis fairly soon, in which case the inhibition or control over the infra-granular cortex being diminished or removed, there might follow certain anti-social reactions in which the more purely animal instincts play a part. It is certain that the pyramidal cells of the supra-granular cortex are the first to go to sleep, and are the first to show the effects of alcohol. In the former case there may follow, with the removal of inhibition consequent on the partial cessation of function of these supra-granular pyramidal cells, disordered mental functioning in the shape of dreams, and in the latter, there may be displays of sexual phenomena consequent on the now unrestrained activities of the infra-granular cortex. With the extension of sleep to still deeper layers of cortical cells, or complete alcoholic poisoning of all the cortical layers, there will be dreamless sleep or alcoholic coma without any effector responses whatsoever.

The Clinical and Social Importance of Cortical Histological Stratification. As a result of this recent modern study of cortical histology, and the functioning of nerve cells in horizontal planes, there begins to emerge the highly significant fact that in every human individual there is an inner or infra-granular brain of the animal instincts and activities, and an outer or supra-granular brain of control, inhibition, and educability. Bolton has clearly proved that the neurons of the latter develop late and are extremely variable in numbers in

different individuals, hence it follows that some individuals will react to their social environment on a more nearly animal basis than others, and there thus appears to be an established physical basis for many social problems, such as, certain phases of crime, prostitution, and general social inefficiency. In cases of mental alienation, grading from idiots and imbeciles, through various types of amentia, great differences in the thickness and numbers of neurons of the supra-granular cortex, have been quite definitely established, both macroscopically and microscopically. In amentia the condition is one of under-development of the cortical layers, particularly the supra-granular, whilst in dementia there is a destruction of such cells, and the destruction affects the layers in the reverse order to that of their evolution and development, the most affected being the latest developed, and the least affected being the earliest developed.

Bolton believes, as does the author, that this physical basis of the cerebral functions of mind, which exhibits such well-marked variations in the subjects of mental alienation, exhibits equally important, though less extensive, variations in the case of presumably normal individuals; and thus indicates the strong probability of a structural origin for individual differences in mental endowment.

It is thus clear that cortical histology is an extremely important subject, and that its teachings are of the utmost significance in the study of the reaction of the individual to his social surroundings, in the practice of medicine, in the study of mental disease, and in the phenomena of everyday social life.

CHAPTER XXVII

THE ONTOGENETIC DEVELOPMENT OF THE LAYERS OF THE CEREBRAL CORTEX

Prenatal Development of the Layers of the Cerebral Cortex. At the *fourth month of foetal life* the cerebral cortex consists of an internal or deep undifferentiated mass of neuroblasts, on the outside of which is the outer fibre lamina, which at this period is about one-half of the adult depth, and remains unchanged until the development of lamination in the sixth month. At birth, the outer fibre lamina has attained to a depth which is about two-thirds of the adult normal. It is probable that its further development to the normal adult depth occurs in association with that of the subjacent second, pyramidal or outer cell lamina.

By the *sixth month of foetal life* development of the cerebral cortex has proceeded sufficiently far as to permit of the recognition of the several layers of the cortex and even of their micrometric measurement.

The *inner or polymorphic cell lamina* (infra-granular) is the first of the cortical cell layers to appear, and by the sixth month of foetal life, is definitely separated off from the rest of the partially differentiated neuroblasts of the cortex by the development of the fourth or inner fibre lamina. At this early period, then, the infra-granular cortex has already attained to about 75% of its total adult micrometric depth, and six weeks after birth the thickness has increased to 82% of the adult normal. Thus early is the brain prepared for those functions necessary for the preservation of the individual and the species.

The *granular or middle cell lamina* develops in the sixth month of foetal life, and at this period it is separable from

the superjacent outer or pyramidal cell lamina (supra-granular) by the more differentiated condition of its cell elements. At this period it is already one half of the adult depth, and by the time of birth it has attained to a depth which is nearly three-fourths of this.

The *outer* or *pyramidal cell lamina* is the last cell layer of the cortex to develop during the process of lamination. In a foetus of six months this layer is separable from the subjacent middle or granular cell lamina by the less differentiated condition of its cell elements, and it is at this period only one-fourth of the depth to which it attains in the adult. At birth and in early infancy it is still little more than one-half of the adult depth. It gradually increases in thickness, and in an infant of six weeks has attained to a depth which is about 60% of the normal.

As regards the *inner fibre lamina*, coincident with the inner line of Baillarger which is composed of incoming medullated axons, it appears in the sixth month of foetal life, and almost at once attains to nearly the normal adult depth, that is, receptor axons myelinate early and thus early pour nerve impulses into the brain. The early development and differentiation of this axon layer quickly effects a cleavage in the partially differentiated neuroblasts of the cortex, and early divides them into a supra-granular series, and an infra-granular series, and this cleavage of the neuroblasts is an occurrence of the greatest significance.

Correlation of Cortical Development with Evolution and Function. From the foregoing account, based on Bolton's researches, of the ontogenetic development of the cortical layers of the human brain, it is clear that development coincides with both evolution and function. By the early development of the primary *inner fibre lamina*, or inner line of Baillarger, which attains nearly the normal adult depth at the sixth month of foetal life, provision is made for the subsequent inpouring of extero-ceptive and other receptor impulses essential to life and consciousness.

It is to be further noted that the *infra-granular cortex*,

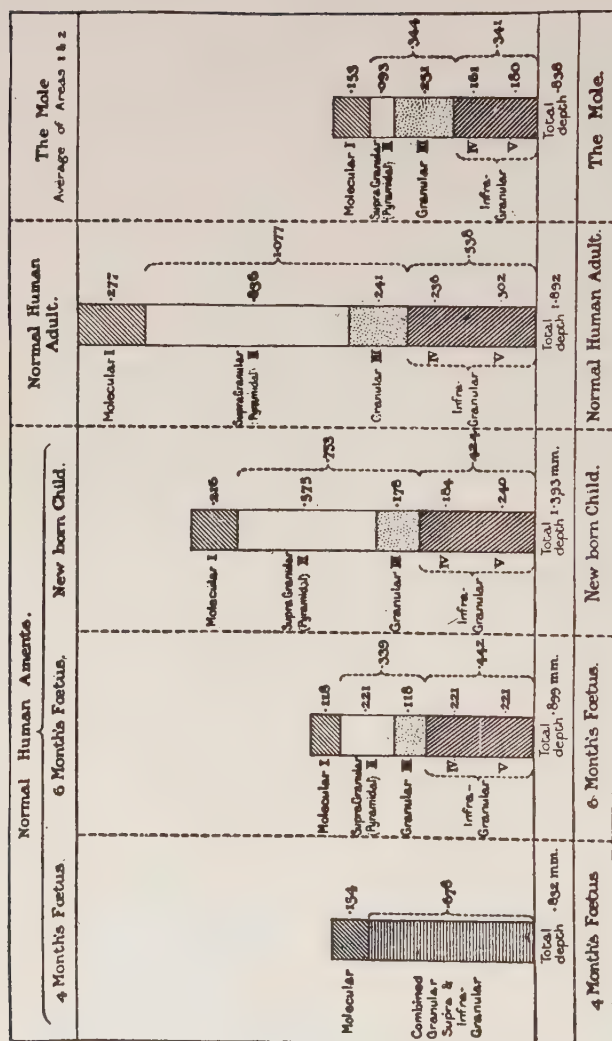


Fig. 106.—Illustrates approximately the relative depths of the cerebral cortical layers in normal human amegs (four and six months' foetus and new-born child), the normal human adult, and the mole. (G. A. Watson, 1907).—The micrometric measurements in the first four cases are taken from the "Histological Basis of Amnesia and Dementia" (Archives of Neurology, vol. II, 1903) by J. Shaw Bolton; those of the cortex of the mole are also by Dr. Bolton. Supra-granular (pyramidal) layer left blank; infra-granular (IV and V) shaded darkly. (From: Hill, "Further Advances in Physiology.")

which presides over the lowest bodily functions, such as those concerned in the getting of food, the sexual instincts, and so on, develops and attains maturity long prior to the more recently evolved brain of control, inhibition, and educability. The human being is thus early provided with the requisite nerve machinery for the functioning of those purely animal characteristics necessary for the preservation of the individual and the species.

With the brain of control, inhibition, and educability—the *supra-granular cortex*—it is, however, very different. This is the last layer of the cortex to be evolved, the last to commence to develop, the last to attain maturity, and consequently the first to undergo retrogression. From the evolutionary standpoint, having been recently added, it is in a state of instability. It is the only cell layer of the cerebral cortex which varies definitely in measurable depth in normal brains, that is to say, it is the only cortical layer in which the numbers of cells differ very appreciably in different individuals. It is underdeveloped to different degrees, according to the mental capacity of the individual in persons exhibiting various grades of mental sub-evolution, and it undergoes degrees of retrogression which correspond to the amount of dementia existing in cases which permanently suffer from diminution or loss of their mental power.

The animal instincts are, therefore, as well developed in man as in any other animal, and are of an essentially similar nature, especially as regards the manifestations of hunger and sex; indeed, as regards the latter they are probably even more clamant than in any other animal. In the human being, consequent on the acquisition and development of a brain of inhibition and control—the *supra-granular cortex*—the effector responses to the receptor stimuli of hunger and sex, differ from those of any of the lower animals, because they are capable of being inhibited and controlled—always provided that the brain of control is properly developed. But Bolton's work, supported and substantiated by subsequent clinical evidence, has clearly proved that the development of this con-

trolling cortical layer differs very considerably in different individuals and under different conditions of health and disease. It is these differences in the state of development of the controlling or inhibiting supra-granular cortex which underlie many mental and social phenomena, some, if not all, of the neuroses and psychoneuroses, as well as many forms of mental disease and so-called mental deficiency.

The Nervous System at Birth. It is important to remember, though it is frequently forgotten, that at birth the nervous system is in a very embryonic or undeveloped state. The new-born child is an unconscious, reflex organism, and only those neurons are fully matured which are absolutely necessary for the maintenance of organic life. The act of defæcation is, in the first months of life, for example, purely reflex, automatic, and unconscious, because at this time those neurons, other than the autonomic, governing the voluntary rectal functions are unmyelinated, and no medullated neuron can function until myelination is complete.

With post-natal myelination of the rectal neurons of the central nervous system comes conscious voluntary control over this, and similar vital acts. So with the brain. At birth the brain has attained about 25% of its total adult volume, and most of its neurons, particularly those of the supra-granular cortex, are in an undeveloped, embryonic condition, and this is particularly the case with the association areas. It is perhaps no exaggeration to state that, at birth, the majority of the supra-granular brain cells are in the embryonic neuroblastic condition, quite incapable of functioning until subsequent development converts them into myelinated neurons, and this process will be very seriously retarded, or even arrested altogether, if the suitable receptor stimulus be inhibited, hence that form of idiocy known as idiocy from deprivation of the senses. In the normal child, however, this post-natal cortical development should take place early and quickly as may now be set forth.

Post-natal Development of the Laminæ of the Cerebral Cortex. Bolton and others have shown that, at birth, or

within a very few weeks after birth, the infra-granular cortex has attained to 82% of its adult thickness, whereas in the newborn child the supra-granular cortex is only one-half the thickness it should ultimately attain. Differently expressed the majority of the infra-granular neuroblasts have, at birth, completed their development as mature neurons, whereas only a minority of the supra-granular neuroblasts have so completed their development. Future increases in the depths of the cortical layers, of the numbers of neurons developed from neuroblasts, of the post-natal increase in brain and head size, must, therefore, clearly concern almost entirely the supra-granular cortex. It has long been known that post-natal increases in brain weight and size are largely due to medullation.

Basing their studies on the cortical work of Bolton and Watson, Berry and Porteus endeavoured to study this post-natal rate of growth of the supra-granular cortex by observing the annual increments in head size from birth to the third decade of life, and calculating therefrom, by Pearson and Lee's formula, the cubic capacity of brain of the living child. The table on page 378 from these Authors' "Intelligence and Social Valuation" shows what this capacity should be in the normal Australian boy or girl at all periods of life from birth onwards.

The figures in this table, based on 10,000 living beings, combined with the facts already adduced as to the pre-natal development of the cortical layers of the brain, are strongly suggestive that post-pubescent cerebral growth must be almost entirely concerned with the final development of the superficial pyramidal cell layers of the cortex, that is, of the supra-granular brain of inhibition, control, and educability. If, therefore, an adult possess a brain capacity of an eleven- or twelve-year-old boy, it is more than a justifiable inference that his supra-granular cortex has been partially arrested in its development, and the consequences to society will then depend on his environment, hereditary history, and education.

If the pre-natal observations on the cerebral cortex be now

GIRLS				BOYS			
Year of Life	Cubic Capacity of Brain in C.C.	Percentage Volume of Brain	Periodical Increment of Brain Growth	Cubic Capacity of Brain in C.C.	Percentage Volume of Brain	Periodical Increment of Brain Growth	Phase of Sexual Life
Birth	333	25.0		371	25.0		Pre-Pubescent Phase
1st	849	63.7		945	63.7		
2nd	966	72.5		1075	72.5		
3rd	1035	77.6		1151	77.6		
4th	1066	80.0		1186	80.0		
5th	1096	82.2		1206	81.3		
6th	1121	84.1		1225	82.6		
7th	1146	85.6		1244	83.9		
8th	1162	87.1		1264	85.2		
9th	1173	88.0		1283	86.5		
10th	1199	89.9		1301	87.7		
11th	1217	91.3	91.3	1317	88.8	88.8	
12th	1226	91.9	0.6	1326	89.4	0.6	Resting Phase
13th	1257	94.3		1351	91.1		Pubescent Phase
14th	1271	95.3	3.4	1358	91.6	2.2	
15th	1279	95.9		1378	92.9		Post-Pubescent Phase
16th	1304	97.8		1402	94.5		
17th	1305	97.9		1422	95.9		
18th	1307	98.0		1447	97.6		
19th	1324	99.3		1463	98.6		
20-30	1333	100.0	4.7	1483	100.0	8.4	

combined with the post-natal researches of Berry and Porteus on the living subject, there results the complete picture on page 379 of the rate of development of the cortical layers of the brain:

This table seems to make it clear that post-natal brain development is chiefly concerned with growth of the all-important pyramidal neurons of the controlling supra-granular cortex. In an ordinary normal human brain it has been estimated that there should be 9280 million neurons, which, with the supporting neuroglia, make up that brain. Assuming that only one-third of these belong to the pyramidal cell layers it is obvious that if they fail to attain complete development, that is, to pass from the neuroblastic condition to the neuronie, the individual will tend to have a smaller head and brain and a corresponding diminution of intellectual and

ONTOGENETIC DEVELOPMENT OF THE CORTICAL LAYERS
OF THE BRAIN

Period of Life	Infra-granular Layer	Supra-granular Layer	Volume of Brain
4th month foetus	Undifferentiated neuroblasts	Superficial indifferent cells	
6th month foetus	75 per cent. of adult thickness	25 per cent. of adult thickness	
Birth	Has remained almost stationary	50 per cent. of adult thickness	25 per cent. total volume
6 weeks old	82 per cent. of adult thickness	60 per cent. of adult thickness	
1st birthday			63.7 per cent. total volume
2nd birthday			72.5 per cent. total volume
4th birthday			80.0 per cent. total volume
13th birthday			91.1 per cent. total volume

inhibiting power. His reactions will approximate more nearly to the animal level. It is proved beyond question that it is to this class of cerebrally underdeveloped ament that so many criminals, prostitutes, and hysterical individuals belong, and it is further proved that it is the pyramidal cell layers of the cortex which, in these cases, show the greatest change in their histological construction.

CHAPTER XXVIII

THE LOCALISATION OF FUNCTION IN THE CEREBRAL CORTEX

Dangers of the Doctrine of Cerebral Localisation. Whilst it is undoubtedly true that different portions of the cerebral cortex fulfil specific functions, it must not be forgotten that, structurally and functionally, different parts of the brain are so intimately connected as to make it not improbable that injury, or defect from maldevelopment or ill health of the cortical neurons, in any one part may influence prejudicially the functional value of all other regions in the brain.

The generalised idea of a localisation of function has long been accepted, but the modern neurological view is that the human brain is composed of a multiplicity of neurons, anatomically independent, but functionally working together as a physiological entity. Interference, therefore, with any group of cerebral neurons impairs the functional value of the whole. Once cerebral neurons have been destroyed they can never regenerate and the brain is correspondingly impaired.

Herrick expresses this important conception of the functional entity of the human brain as follows: "the general conclusion to be drawn from the entire series of physiological and pathological studies of the cortex is that specific mental entities are not resident in particular cortical areas, but that cortical functions involve the discharge of nervous energy from one or more sensory centres to various near and remote regions, each of which, in turn, may serve as a point of departure for new nervous discharges, and so on until the complexity of action and interaction of part upon part becomes too intricate for the mind to conceive. The resultant effect of all these nervous activities which reverberate from one association centre to another will be the establishment of some

sort of a neural equilibrium which finds its expression in a definite motor act or an idea."

Clinical Importance of the View that the Brain is a Functional Entity. It is not infrequently assumed that minor lesions of the brain, from which the patient recovers, as, for example, a slight hæmorrhage, leave no permanent effects upon the patient's mentality. The view is a mistaken one. There are few, if any lesions of the brain, which do not subsequently impair the mentality. Von Monakow's doctrine of *diaschisis* (from the Greek, a splitting apart) is based on this fact that the brain works as a whole, and that no one part can be damaged without impairment of the whole. Herrick, in discussing this doctrine says, "the onset of cerebral hæmorrhage or any other sudden injury to the cerebral cortex is usually marked by an apoplectic 'stroke,' with profound shock and usually loss of consciousness. The entire cortical equilibrium is disturbed and this effect irradiates very widely throughout the nervous system. If the injury is not too severe, there is soon a partial readjustment of the nervous equilibrium and consciousness returns. But the restoration is incomplete, for some of the normal factors in the dynamic equilibrium complex are lacking by reason of the destruction of the corresponding cortical areas or association tracts. The intelligence is enfeebled and all voluntary control is impaired. . . . The immediate shock-like interference with the activity of cerebral centres not directly affected by the lesion is what von Monakow means by diaschisis. Upon the restoration of the nervous equilibrium this transient diaschisis effect is wholly or partially lost, and the residual symptoms of defect give a fairly accurate picture of the intrinsic functions of the centre directly attacked by the lesion."

On account of the intricate character of the neuronie pattern of the cerebral cortex it is most improbable that the exact routes followed by the passage of nerve impulses through them will ever be known with absolute certainty, though there is no doubt that they conform generally to the laws which govern the conduct of nerve impulse in other and simpler parts of the

neuraxis. The view, therefore, which should govern the conception of cerebral activity, is not that currently held of isolated parts, such as "motor" centres acting independently, but rather should the brain be compared to a vast irrigation system through the channels of which nerve impulse flows. Damage one or more of the channels and there is an interference with the flow. Some channels will now receive none, and others will be charged with the pent up impulses which will be discharged along abnormal routes. That something of this sort takes place in the human brain is pretty certain, and is nearer the truth than the currently accepted belief of independent areas working apart.

The Physical Functional Areas of the Human Cortex. Subject to these important reservations the physical functional areas of the human cortex may be set forth as follows:

The precentral motor and the intermediate precentral psychomotor areas.

The postcentral somaesthetic and the intermediate postcentral somaesthetic-psychic areas.

The calcarine or visuo-sensory and the occipital or visuo-psychic areas.

The temporal audito-sensory and the intermediate temporal audito-psychic areas.

The olfactory area.

The taste area.

The Precentral Motor Area. The precentral motor or Rolandic projection area is characterised histologically by the presence, in its large pyramidal cell layer, of the *giant pyramidal cells of Betz*, and by the absence, or feeble development, of the granular cells. The area is situated within the precentral gyrus, in close relationship to the central sulcus of Rolando and extends over on to the medial surface of the hemisphere. It thus coincides fairly closely with area 4 of Brodmann's charts. It is from the large pyramidal cells of this area that the nerve impulses governing voluntary muscular movements on the opposite side of the body are generated. The area is subdivided into lesser areas, each of which controls the muscles moving a given part of the opposite half of the

body, and here found in inverted order. The area for the inferior extremity is situated on the highest part and is continued over on to the adjacent paracentral lobule of the medial surface of the brain. That for the trunk occupies the upper part of the area; the superior extremity the middle part; for the face the lower part of the area; for the tongue, larynx, muscles of mastication, and pharynx, the frontal operculum; and the areas for the head and neck, the occipital end of the middle frontal gyrus.

The precentral gyrus is one of the chief cortical areas for the initiation of effector impulses to voluntary muscles, or, in other words it is the cortical cell station of the upper motor neurons of the cortico-spinal and cortico-bulbar tracts. In the same way the postcentral gyrus is the main cortical receptor area for incoming receptor impulses, and these differences in function are reflected in the details of their histological structure.

In the precentral gyrus, the grey matter is thick on account of the largeness of its cell bodies, and the lines of Baillarger are broad and diffuse, because many myelinated axons from other cortical regions are here converging on the effector cells of the area. The granular layer, which is one of the chief storage areas for receptor impulses is here almost entirely absent, so that the large pyramidal cell layer of the motor area is a single one and forms the giant pyramidal cell layer of Betz.

The giant pyramidal cells of Betz are the cells of origin of the cortico-spinal and cortico-bulbar tracts. They have been counted in the human cortex, as have also the numbers of medullated axons in the pyramidal or cortico-spinal tracts, and the numbers of both are in tolerably close agreement—about 80,000 on each side. The axons of the giant pyramidal cells of Betz pass, as the upper motor neurons of the clinician, through the corona radiata, the internal capsule, the base of the peduncle or crusta, the basilar part of the pons, the pyramids of the medulla, the decussation of the pyramids, and the anterior and lateral cortico-spinal tracts of the spinal cord, to

end in a synaptic junction around the cell bodies of the lower motor or final common effector neurons.

Although the precentral motor area contains the cells which generate the impulses responsible for the actual volitional movements of striated muscles in accordance with the will, it must be remembered that these Betz cells only do so in response to many other nerve impulses coming to them from many adjacent and distant parts of the cortex. Each impulse arising in such a cell is, therefore, the result of a vast number of stimuli convergent upon it from other neurons. It is, therefore, practically certain that nearly every special area of the cortex, if not every part of the cortex, participates and influences the formulation of the motor reaction, and this reaction may result from either receptor impulses passing in at the precise moment of the reaction, or in response to other impulses which have reached the brain long antecedent to the time of the reaction and have been stored up in granular or other storage cortical cells.

Another important function of this part of the cortex, though one not yet fully understood, is that of *inhibition*, that is, it appears to be able to prevent other effector impulses passing through to the muscles. When the area is defective or destroyed, this inhibitory control appears to be lost, and the muscles concerned pass into a condition of hypertonus or spasticity, which appears to denote that, on account of the destruction of the restraining influence of the giant pyramidal cells of Betz, other impulses are now getting through to the muscles, causing the spasticity referred to.

The *intermediate precentral psycho-motor area* occupies a part of the frontal cortex immediately frontal to the previous area, of which it appears to be a slightly modified histological replica. Within this area is situated the neuronie mechanism for the acquisition and retention of skilled muscular acts.

The Postcentral Somaesthetic Area. By the postcentral somæsthetic area is meant the portion of the cortex to which general sensations from the surface of the body and the deeper tissues are first projected. The area is not, therefore, to be regarded as the terminal station of such impulses, but only as

their cortical "shunting" station. It is generally located in the posterior central gyrus, and corresponds to Brodmann's Areas 1, 2, and 3. It receives axons belonging to the thalamic radiation from the lateral nucleus of the thalamus, which represents neurons of the third order transmitting receptor impulses from the skin, muscles, joints, and tendons.

The *intermediate postcentral somæsthetic-psychic area* lies on the immediate occipital side of the previous area and apparently serves as an elaborating area for the association and transformation of receptor impulses into conscious perception

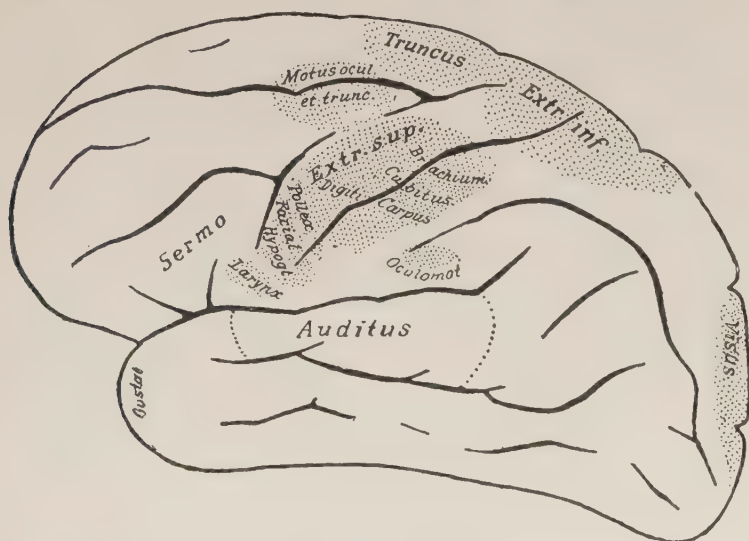


FIG. 107.—Sensory-motor area of human cerebral cortex. The cortex of the paracentral lobe of the mesial surface, which is not visible in the figure, also forms part of the sensory-motor area. (From Luciani, "Human Physiology.")

thereof. In lesions of the area the most positive and invariable symptom is diminution of stereognostic perceptions, that is, of the power of judging the form and consistency of external objects when handled. This test is one of the few purely neurological tests employed by the well-known Binet method and is of considerable value in estimating underdevelopment of the child's cortex. The young ament usually fails badly at this test, and the fact is thus strongly suggestive of a cerebral underdevelopment.

The receptor pathways by means of which impressions located in the "body-sense" area travel may be summarised thus:

The peripheral nerves.		
The gracile, cuneate, spino- thalamic and possibly other tracts of the spinal cord.	}	Spinal cord neurons.
The arcuate fibres.	}	Intermediate neurons.
The decussation of the fillet.		
The medial or sensory fillet.	}	Cerebral neurons.
The thalamo-cortical fibres.		

Lesions of *the spinal cord neurons* are common, and usually take the form of tabes dorsalis or locomotor ataxia, which occurs most frequently in adults who have previously suffered from syphilis.

Diseases due solely to degeneration of *the intermediate and cerebral neurons* are practically unknown.

The Calcarine or Visuo-sensory Area. The visuo-sensory area is situated within that part of the occipital cortex which bounds the calcarine sulcus, and forms the true cortical terminus of the optic nerve fibres. The visual area sometimes extends round the occipital pole on to the lateral surface of the brain.

The visual cortical area is very characteristic. It is more than one-half as thick as the motor cortex, and the outer line of Baillarger is greatly increased in thickness and is here known as the stria of Gennari. This white line is composed of medullated visual receptor axons, and is such a prominent feature of the visual area as to confer upon it a striated appearance, hence the name of *striate area* so frequently applied to the visual cortex. The striate area is surrounded by cortex of quite different histological appearance, and the stria of Gennari terminates abruptly at the junction of the striate area with the surrounding areas. The presence of the stria of Gennari is so absolutely characteristic of the visuo-sensory area that the extent of such cortex may be determined

anatomically by mapping out the region in which it occurs. The stria of Gennari lies in the middle of the well developed granular portion of the cortex, which it thus divides into two, making the former appear double. In *congenital blindness*, the stria of Gennari, and that part of the granular layer which lies superficial to it, are diminished in depth, sometimes by as much as 50%. This also occurs in old-standing cases of optic

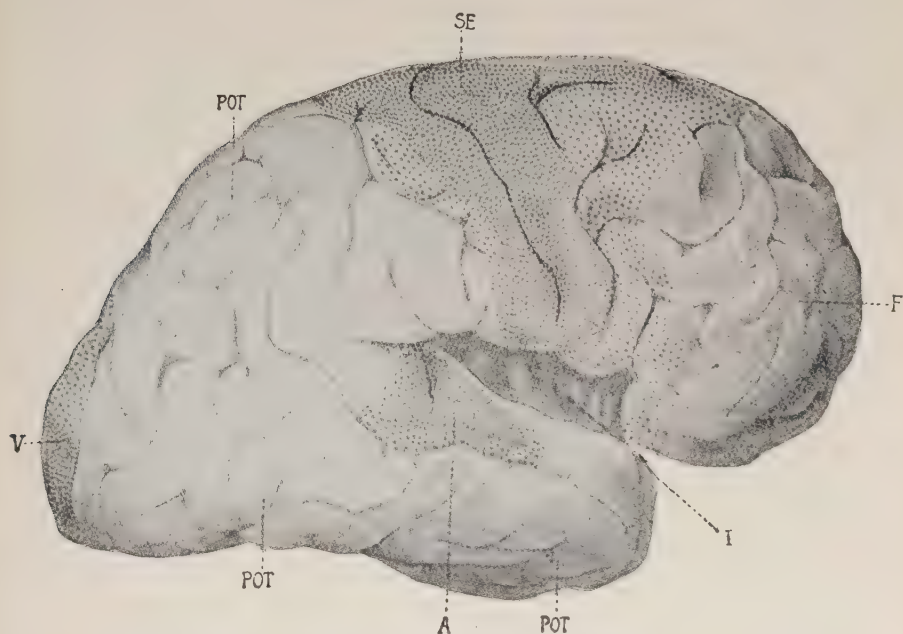


FIG. 108.—Diagram of projection and association areas. (From Flechsig.) *SE*, sensory-motor area; *V*, visual area; *A*, auditory area; *F*, frontal association area; *I*, association area of insula; *POT*, parieto-occipito-temporal association area. (From: Luciani, "Human Physiology.")

atrophy. The importance of the visuo-sensory area as a receptor area for visual impressions is also borne out by the early and rapid development of the neurons and cell-layers concerned.

Around the striate or visuo-sensory area, are the para-striate and peri-striate areas, functionally also termed the *visuo-psychic area*. In this zone the superficially superadded por-

tion of the granular layer of the cortex suddenly ceases, but the supra-granular pyramidal cortical cells are better developed. The structure of the visuo-psychic area is not modified by blindness.

Receptor impulses destined for the visual area traverse a series of neurons. The *first* of these is that of the optic nerves, the axons of which run through the optic nerves, chiasma, and

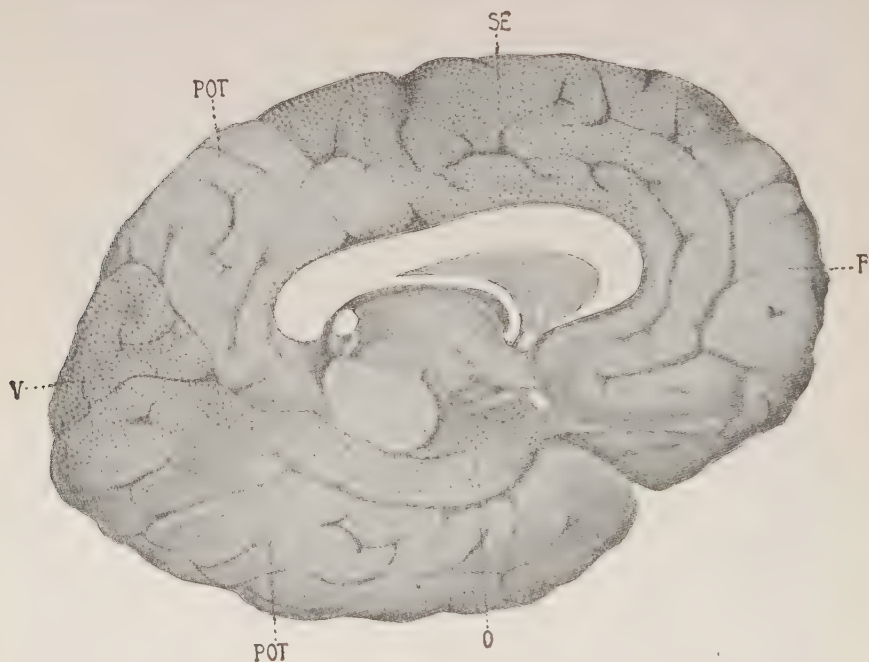


FIG. 109.—Plan of projection and association centres. (After Flechsig.) *SE*, sensory-motor area; *V*, visual area; *A*, auditory area; *F*, frontal association area; *I*, association area of insula; *POT*, parieto-occipito-temporal association area; *O*, olfactory area. (From: Luciani, "Human Physiology.")

tracts, as both crossed and uncrossed fibres, to terminate in the grey matter of the lateral geniculate body, the pulvinar of the thalamus, and the superior colliculus. Here arise a *second* series of neurons whose axons constitute a special bundle, the thalamo-occipital radiation, which traverses the internal capsule to reach its destination within the occipital cortex. The results of the decussation and non-decussation of visual neurons within the optic chiasma are that the right occipital lobe

constitutes the visual area for the two right halves of the retinae, and the left occipital lobe constitutes that for the left halves.

In addition to the receptor fibres passing to the visual area, there appear to be *effector* fibres passing from the visual area to the midbrain, where they make connections with the nuclei of the effector nerves of the eyeball, and possibly others proceeding to the rods and cones.

The subdivision of the visual cortical area into visuo-sensory and visuo-psychic parts attains its highest development in man. The former, as stated, coincides with the main terminations of the neurons conveying light impressions from the retinae, and is, therefore, almost certainly, the place where such impulses are received and stored, whilst the latter interprets and fuses the impulses with those received from other sources.

The Auditory Area. The general auditory area is situated within the cortex of the middle third of the superior temporal convolution and the adjacent portion of the opercular surface of the temporal lobe. Like the visual area, it comprises two parts, audito-sensory and audito-psychic. The former occupies the anterior and posterior transverse temporal gyri of the opercular surface; the latter the surrounding pars intermedia and pars circumambiens. The path of the cochlear nerve of hearing to the cortical area concerned has been fully set forth on page 205.

The Olfactory Area. The olfactory area is situated in the uncus and adjacent portions of the hippocampal gyrus, and within it terminate the axons of the lateral olfactory stria.

The Taste Area. The taste area has not been definitely localised, nor are its central connections known with certainty. It is usually believed to be situated in the hippocampus.

Conclusion. "In the present state of our knowledge of cortical activity and its relation to consciousness it is the part of wisdom to be very conservative in locating any mental faculty or fraction of our conscious experience in any particular part of the cerebral cortex. . . . Destruction of these areas (audi-

tory, visual, olfactory, etc.) causes impairment or loss of the corresponding sensations with reference to the opposite side of the body or the opposite half of the field of vision. Total loss of cutaneous sensibility even within circumscribed areas never results from cortical lesions; and it seems probable that the thalamic centres are in themselves sufficient for a certain low grade, non-discriminative consciousness or awareness of cutaneous stimulation. This is particularly true of painful sensations, which seem to be for the most part of thalamic origin. (Head, 1918.) Furthermore, the various parts of the cerebral cortex are so intimately linked together by association fibres that when afferent (receptor) impulses reach a given projection centre they must not only activate this centre, but be propagated to other parts of the cortex as well." (Ranson.)

CHAPTER XXIX

THE BRAIN AS THE PHYSICAL INSTRUMENT OF MIND

Neurons the Physical Instruments of "Mind." That the brain is the physical instrument of all those phenomena, such as speech, reason, thought, consciousness, wisdom, intelligence, etc., which collectively make up "mind" is a fact which cannot be legitimately questioned. A severe blow on the head, after which these phenomena are temporarily in abeyance from transient damage to the cerebral neurons is, in itself, sufficient to prove the point, quite apart from those numerous other factors, such as developmental errors, poisons, diseases, injuries, and the like, which are known to alter the mental phenomena by damaging or impairing their physical instrument—the brain.

As the brain is known to consist only of neurons embedded in neuroglia it is clear that neurons in combinations of chains and arcs are the physical instruments of mind. Morphology, comparative anatomy, and embryology further prove that man only differs, physically, from the lower animals in the fact that he possesses about three times as many cerebral neurons as does any other animal, and that, therefore, his increased mentality is solely due to this cause.

The Association Areas of the Human Brain. Those areas of the human brain which are known to possess a definite physical function have been discussed in the last chapter. They occupy but a relatively small amount of the total cortical area, forming islands, as it were, surrounded by other areas, which eventually shade off into what have been termed by Flechsig, *association areas*.

The term "association area" has been, and still frequently is, employed to designate all those parts of the cerebral cortex

to which an actual physical function is not ascribed. For example, all that portion of the frontal lobe which lies in front of the precentral sulcus is often loosely referred to as the frontal association area, and all that part of the parietal lobe which lies behind the postcentral sulcus is similarly termed the parietal association area. The use of the word "association area" in this sense is erroneous and out of date. It is now known that each functional area gradually shades off into the true association areas, which are thus smaller in actual extent than the more loosely employed term would imply.

The presence of the true association areas is one of the special characteristic features of the human brain, and it is, therefore, certain that these areas play an important part in the production of those higher mental phenomena which distinguish man from many of the lower animals. In other words, these true association areas are the cortical areas of speech, thought, and all that that implies.

As thus defined, and as supported by Flechsig's developmental studies, the true association areas of the human brain *are not provided with projection fibres*, that is, they are not connected with underlying parts of the nervous system, but only with each other, by means of associational and commissural neurons, which it is known are among the very last of the cortical neurons to myelinate.

The foundations of all knowledge are to be found in the sensations aroused through the various sense organs. It is through these avenues alone that consciousness comes into relationship with the external or physical world and the internal or bodily world, and the union of these impressions into organised knowledge is, according to Flechsig, the special function of the association areas. Within these areas the memory records of past experiences are stored up in the cortical network of neurons. If the cortical neurons are grossly deficient, as in the microcephalic idiot, there can be no memory. If these same neurons are deficient to a less degree, as in the low grade ament, the acquisition of speech, which depends on a

charging by suitable impulses of cortical neurons, will be greatly delayed and the subsequent memory will be poor. Intellectual differences between more normal individuals are brought about, first, by the number of cortical neurons possessed, and second, by the nature of the receptor impulses which charge or stimulate those neurons. Special talents are due to special differences in structural organisation of special cortical areas, and if this unequal cerebral development be carried to excess the reactions of the individual to his surroundings may be fraught with danger to his fellows. He becomes, what is sometimes termed, a psychopath.

Myelination of the Association Area Cortical Neurons. Flechsig's study of the functional subdivision of the cerebral cortex is based upon the periods of myelination of the axons of the cortical neurons between the fourth month of intra-uterine life and the fourth month of extra-uterine life. From such studies he has been enabled to differentiate about 36 cortical areas which fall into three great groups.

The areas of the cerebral cortex, in which myelination first occurs, are those of the *primary sense zones*, that is, those areas of the cortex which have physical functions as described in the previous chapter. Of these primary sense zones Flechsig recognises seven or eight, and they are all provided with receptor and effector projection axons.

Around these primary sense zones, myelination next occurs in cortical regions termed *marginal* or *border zones*. These do not possess projection axons, but become connected, as myelination proceeds, with one or more of the primary sense zones, by short association fibres.

In both the primary sense zones and the marginal or border zones myelination is completed, or should be, before birth, and thus the individual is prepared for the carrying out, after birth, of those functions upon which life depends. Cortical development here shows that provision is first made for the receipt, within the cortex, of the receptor impulses, and second, for the storage and diffusion of these impulses within adjacent cortical areas.

Lastly, come the great *association areas* themselves, the axons of which do not myelinate until after birth, and in some individuals, not at all. It is these areas which constitute the specially distinctive features of the human brain. No other animal possesses them, and the human microcephalic idiot is characterised by an almost complete absence of such areas.

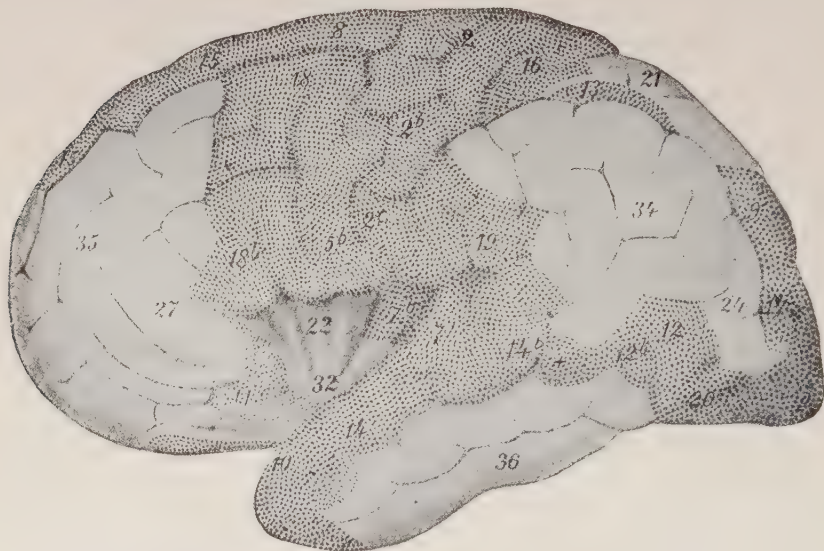


FIG. 110.—Lateral surface of right hemisphere of female infant 54 cm. long, still-born a month before normal period of foetal maturity. (Flechsig.) The explanation refers to this and the following figure. (From: Luciani, "Human Physiology.")

These areas become linked, as development proceeds, with all the receptor and effector cortical areas by long association fibres, hence the name given to them, and eventually with their fellows of the opposite side by the commissural fibres. Flechsig distinguished three such areas, which he terms the frontal, median or insular, and the temporo-occipital.

Flechsig's researches have exerted a profound influence upon all subsequent theories of the functions of the cerebral cortex, although it does not follow that all his conclusions have been universally accepted. Two of his chief conclusions are:

1. The myelinated axons of the brain do not all mature at the same time; those axon systems of like function do, how-

ever, so mature, a fact which constitutes Flechsig's *fundamental myelogenetic law*.

2. In the cerebral cortex there are two great functional groups of fibres which mature at different times. One of these groups contains the *projection fibres*, which mature early, chiefly before birth. The other group contains the *association*

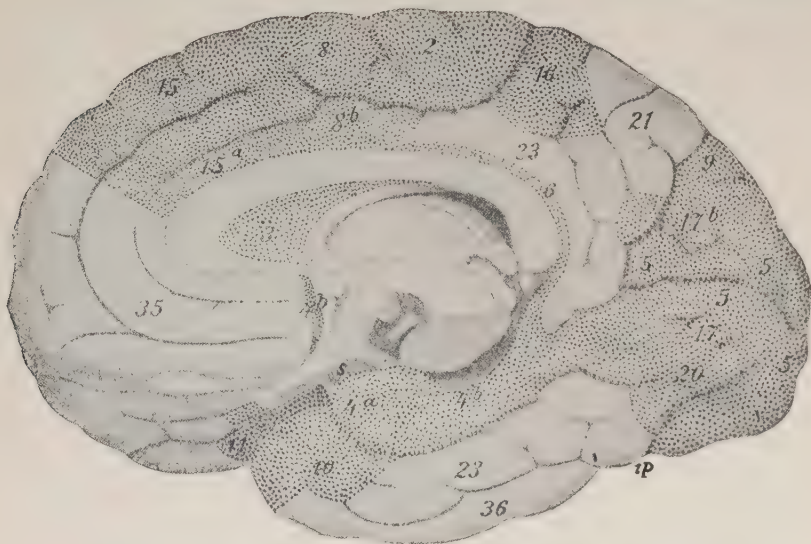


FIG. 111.—Medical surface of left hemisphere of same infant. (From: Luciani, "Human Physiology.")

fibres which mature after birth. These groups are further subdivided into subsidiary functional systems, and the numbers of these agree very closely with those obtained from such totally different lines of study, as the naked eye examination of the stratification of the cortex by Elliot Smith, and the microscopic examinations of the brain cells themselves.

Structure of the Association Areas. It is to be particularly noted that, in their structure, the association areas of the human brain do not differ, in general, from that of any other area of the brain. There are the same five cortical layers with the same types of pyramidal, granular, polymorphic and other short neurons. There can, therefore, be no doubt that, structurally, the association areas are largely composed of

internuncial neuronic tissue interposed between the incoming receptor axons and the outgoing effector, forming, as it were, a species of rheostat between these longer limbs of cortical neuronic arcs. Yet all modern authorities, Starling, Howell, Flechsig, Bolton, Bianchi, and many others, regard the association areas of the human brain as being connected with the higher processes of reflection, intelligence, and volition; as being the true organs of thought; as the regions in which the different sense impressions are synthesised into complex perceptions or concepts; and as being the areas where our memory records of past experiences and their connections are laid down and stored up, in some, as yet, little understood manner, in the inextricable network of neurons of which the association areas are composed. That the higher mental processes undoubtedly require the activity of the association areas is undoubted, as is also the fact that the integrity of the associational mechanism, as a whole, is essential to the full efficiency of mentality. It is of great significance to note, further, that it is exactly these areas which are grossly lacking in the human microcephalic idiot, and that destruction of the frontal association area in the well-known case of the American workman, resulted in such a changed mentality.

Suggested Path of Nerve Impulses in the Cerebral Cortex. What, therefore, happens in the human brain, should, according to structural studies, be somewhat as follows: certain extero-ceptive nerve impulses, such as those of sight, hearing, touch, taste, smell, etc., together with many other impulses from proprio-ceptive and entero-ceptive sources, are conveyed, as regards extero-ceptive impulses, along well established tracts of neurons to certain definite areas of the cerebral cortex, usually of small size, of early myelination, and relatively speaking, as well developed in mammals as in man. Here they are received, and such extero-ceptive receptor cortical areas are known as *sensory areas*, being spoken of as visuo-sensory, audito-sensory, somæsthetic-sensory and so on. Around each of these extero-ceptive sensory areas are others known as *psychic areas*, to which the impulses received in the

sensory areas are transferred, and in which they are, as it were, interpreted, stored, and associated with the psychic areas of other extero-ceptive impulses. Thus there are visuo-psychic, audito-psychic and somæsthetic-psychic areas, etc., linked up with each other and with their own sensory areas. Between these psychic extero-ceptive areas are the still larger silent or association areas, in which are stored, associated and commingled all those entero-ceptive, proprio-ceptive and extero-ceptive impulses which bombard the human brain from birth to death, in health or disease, waking or asleep, and without which there can be no consciousness.

Should these receptor impulses be cut off in any direction, or what gives the same ultimate result, should there be any marked diminution in the cells of the association areas, there will be a corresponding loss of intelligent reaction to the environment. This attains its maximum degree in microcephalic idiocy. Conversely, should there be a localised noticeable increment of cortical neurons in some portions only of the association areas, *without deficiency* elsewhere, there may result a one-sided and limited genius, but if the increment of neurons be associated *with deficiency* elsewhere, there may be an abnormal or psychopathic behaviour, and to this group belong many "cranks" and aberrant social types.

Association Cortical Areas the Storehouses of Memory. If the cortical association areas are the "true organs of thought" (Howell), the seat of "the higher processes of reflection, intelligence, and volition" (Starling), "of special significance for the higher intellectual functions" (Ranson), and that if it is "in the association areas our memory records of past experiences and their connections are laid down in some, as yet unknown, material change in the network of nerve cells and fibres" (Howell), then it appears to be an inevitable conclusion that the granular and other internuncial associational and commisural neurons of the association cortical areas act as storehouses of memory, provided they have been completely developed and have previously received the suitable extero-

ceptive or other stimulus. Once having been so "charged" they may, again under the suitable stimulus, be stimulated to discharge the previously stored up energy and the phenomena of memory are produced.

On neurological grounds it seems to be quite impossible to escape the logical and inevitable conclusion that the association area cortical neurons are the physical storehouses of memory, which have become charged with nerve energy, as the result of the pouring into the brain of entero-ceptive, proprio-ceptive and extero-ceptive impulses. According to Bayliss no fresh neurons are formed during the life of an animal and, when the cell-body of a neuron is destroyed, no regeneration occurs. Any new acquirement in reflex or association must, therefore, be due to the formation of new connections between neurons already present. That is, the incoming impulses gradually take into their neuronics arcs an ever-increasing number of the shorter cortical neurons, and it is this process which is so largely responsible for the transformation of the post-natal dormant neuroblast into the neuron. Memory thus implies the more or less permanent establishment of these new neuronics connections. The possibility of disconnection at a later period must be clearly admitted. It is, indeed, this last fact, that is, the dropping out of the neuronics chain of some of the essential neurons from disease or natural death of the neuron (lack of durability) which explains so many of the mental aberrations met with in mental hospitals, with their disordered manifestations of thought, speech and mind. It is further this "disconnection" or dropping out of the neuronics chain of some of its essential structural units which is manifested, pathologically, in some of the aphasias, and physiologically and occasionally in every individual who "can't think of the word."

Summary. The mode of cortical association between the conducting limbs of neuronics arcs would thus appear to be a much more important subject than has been supposed, and to play a vital part in all mental phenomena. A close study of the structural details by which this is brought about, seems

to lead to some quite new conceptions of memory, mind and speech.

The cerebral cortex is a vast collection of neuronie arcs, with a complex series of internuncial neurons between the limbs of these arcs. In everything but simplicity, these conform to the type found in all vertebrates, and man only differs from the vertebrate in possessing far more of such neurons.

In the more recently evolved supra-segmental portions of the nervous system the mode of union of conducting limbs of neuronie arcs appears to differ from that of the relatively more simple type of the older segmented portions.

These differences in the mode of union appear to be strongly suggestive of the fact that it must be the many short neurons of the supra-segmental portions of the nervous system which have, as their special properties, the storing up, transformation and dispersal of nerve impulse or nerve energy and, consequently, the granular and other internuncial neurons of the cerebral cortex are the physical storehouses of memory. This view appears to harmonise with known neurological evidence, to throw light on many mental processes and functional nervous disorders, and to be not inconsistent with physiological opinion on the possible functions of the neurosynapse.

The association areas of the human brain are the fields for all the higher mental functions, such as thought, memory, reason, and speech. The capabilities of the human individual in these directions will differ according to the number and mode of connection of fully developed functioning neurons within these areas. Special talents are due to difference in organisation of special parts of the cortex. (Howell.) These areas, particularly the prefrontal, are underdeveloped in idiots and imbeciles (low grade aments) and to a lesser degree in high grade aments.

Man is the only animal with well developed association cortical areas. He is the only animal to think, reason, and speak, and he does so because he possesses more cortical neurons than any other animal. If these fail to develop he will be unable to speak, or if, after full development, these cortical neurons

become destroyed by injury or disease he will lose the faculty of speech.

Comparative anatomy, neurology, physiology and pathology, thus all alike lead to certain conclusions:

1. The cortical association areas are made up of enormously complicated internuncial neurons interposed between receptor and effector conducting neurons.

2. Some, if not all, forms of nerve impulses pass through the neurons of these association areas. If directly, an immediate motor or effector response results. If delayed, a future effector response may or may not occur, that is, the impulses have been stored up in the neurons of the area.

3. Therefore, the neurons of the association areas are the physical storehouses of memory and of speech.

CHAPTER XXX

THE ACQUISITION OF SPEECH AND ITS LOSS BY DISEASE

The Wrong Way of Approaching the Problem of Aphasia.

Apart from a few members of the medical profession there are probably no others who give any thought whatsoever to the interesting problem of the loss of speech, that is, aphasia, as a result of disease, and it is not too much to say that even the medical profession approaches the problem the wrong way. It studies the aphasias without having given sufficient attention to the normal physiology of speech and the mode of its acquisition. In this instance, therefore, pathology precedes physiology with the consequent result of confusion and error. It is essential that, before proceeding to the study of aphasia, there should be some attempt to understand the physiological acquisition of speech in the normal child and to correlate this with the underlying physical basis of the neuronie structure of the brain itself. Without this correlation of cerebral structure with the function of speech it is practically certain that the aphasias can never be correctly understood clinically, and it is probably due to this present day lack of correlation that so much confusion exists in their clinical study.

Speech Is Only Intelligible Noise. Apart from the mechanical noises made by many invertebrates it does not appear that any vertebrate lower than the amphibians is capable of making laryngeal sounds, and the reptiles show but little advance over the amphibians in the production of physiological noises. With the birds there is a great advance and many of this order are capable of producing metrical sounds which foreshadow the production of vowels. Most, if not all, of the popular legends attaching to the production of intelligent speech by trained parrots, are legends only, and the fact remains that

even the parrot is only capable of producing certain metrical noises which, to the human brain, appear to be reproductions of some of the noises made by man in the production of speech. The mammals show no advance on the lower animal forms as regards the character of the laryngeal sounds produced, but, on account of their greatly increased telencephalic brain, can often produce these noises as a sign of the particular emotion involved at the moment, as, for example, the barking of the domestic dog at the sight of an enemy, or as an expression of its pleasure at being taken for a walk by its master. Apart from this, no other animal, except man, is capable of reproducing noises in an intelligible manner and in such a way as to convey ideas to the auditor, that is, no animal, not even the anthropoid ape, is capable of speech, man alone excepted, because man is the only animal with a brain large enough for the purpose. It consequently follows that the acquisition of speech is entirely a question of the possession of a sufficiency of healthy, trained cerebral neurons. If these be insufficient, as in the microcephalic idiot, the child will never speak. If there be no training, as in the congenitally deaf mute, speech will again be absent, unless some form of education, other than auditory, can be employed. It consequently follows that a study of the acquisition of speech again involves an intimate study of the cerebral neurons.

The Transformation of Noise into Intelligent Speech as Seen in the Child. At birth the child does not speak. It only makes noises of a purely reflex, unintelligent character, because at birth, the majority of the cerebral cells are in the embryonic non-functional neuroblastic condition. The gradual transformation of the child from a condition of idiocy to intelligent speech has been well set forth by Wyllie in his classical work on "The Disorders of Speech." The first sounds made by the child after birth are those of *crying*, and for many months after birth, these noises are utilised as an indication of hunger, pain, discomfort, and the like. These noises partake largely of vowel sounds, and thus the child first reproduces the condition of many of the lower animals whose noises

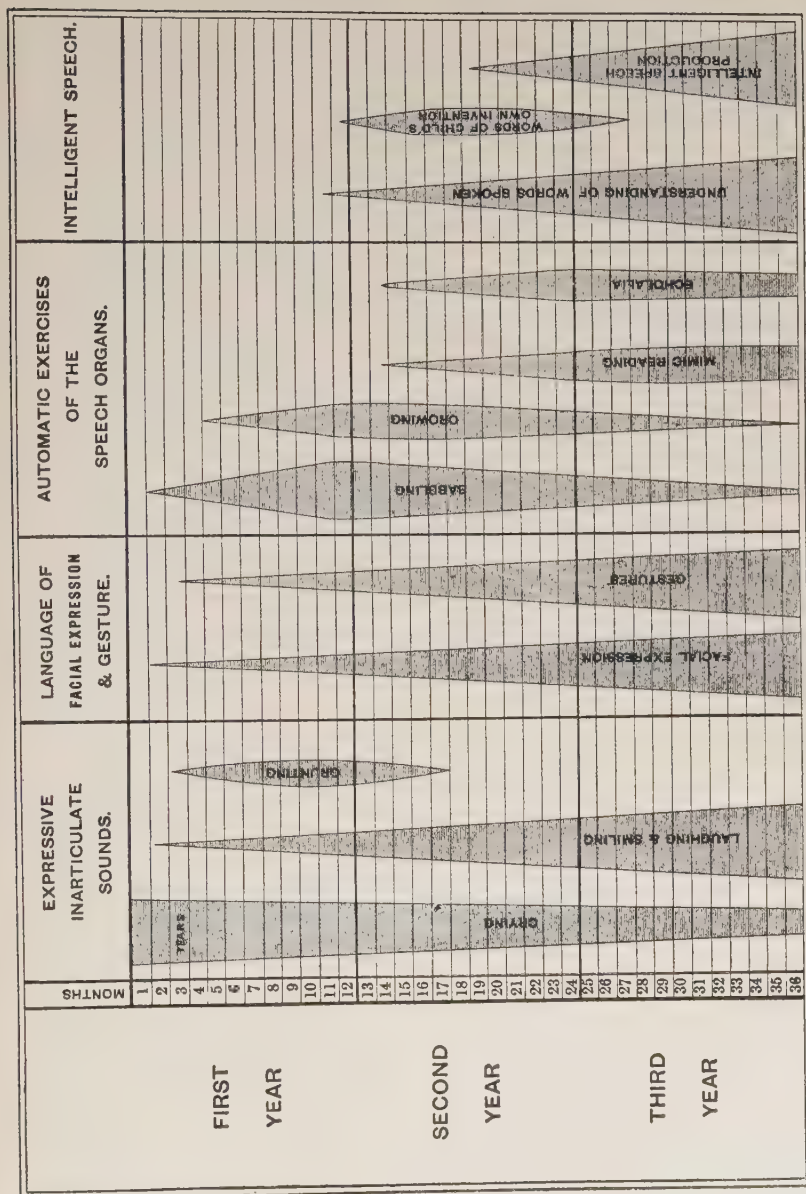


FIG. 112.—A scheme to show how the inarticulate noises of infancy are gradually transformed, with the development of the nervous system, into the controlled sounds of intelligent speech. (From Wyllie's "The Disorders of Speech.")

remain throughout life simple vowel sounds. About the second month the child commences to vary the sounds of crying and adds to its inarticulate sounds those partaking of the nature of *laughter* and *grunting*. *Facial expression*, at first, almost entirely reflex and actuated through the facial nerve muscles, makes its appearance about the second month, and about a month later, the facial expression becomes accompanied by the commencement of *gesture*. At the end of the first or second month the child first exhibits an *automatic* and wholly *unconscious exercise of its speech organs*, which at a future time will become the agents of speech, and this it does by *babbling* and *crowing*, in which phenomena may be noted the production of elementary vowel sounds, and later a few consonants. These preliminary exercises stimulate the cerebral neuroblasts which slowly become developed into functional neurons, so that, at or about the eleventh month, the child commences *to understand simple words*, that is, elementary sounds of a constant character, which are spoken to it. About a month afterwards the child will itself commence to make articulate noises which are mere sound imitations, and are, for the most part, repetitions of the last words in sentences that the infant has just heard. Here both vowels and consonants can be distinguished though the noises produced have no intelligible meaning. They are merely echoes of the sounds heard, and hence this stage in the acquisition of speech is known as *echolalia*. It is of interest to note that this stage of echolalia persists, even in the normal child, until at least the end of the third year of life, and does so coincident with the gradual acquisition of spoken words at command. In many cerebral aments it persists much longer, and hence such patients are often capable of pouring out, by imitation or echolalia, a number of words of whose meaning they are often quite ignorant. This is speech, but is not intelligent speech, though it is frequently mistaken therefor. In the normal child echolalia is acquired and practised before the acquisition of the power of pronouncing any actual words, spontaneously or at command, and the utterance of words or parts

of words by echolalia seems at first to cost the infant much less effort than the pronunciation of words at command. The infant has no idea of the meaning of the sounds it utters and thus the human child passes through a stage which is reminiscent of the so-called talking parrot. The commencement of echolalia is quickly followed, and possibly occasionally even preceded, by the gradual understanding of the simple, elementary words spoken to it. These elementary words are usually of the nature of simple nouns associated with the sight or picture of the noun, thus, the mother points to the father and says "daddy." She is, unconsciously, educating the child's cerebral neurons and is converting the neuroblasts into fully functioning brain cells. Without such education it is important to remember there will be no speech, nor will there be speech if the child's brain does not contain a sufficiency of potential neurons for the purpose.

This stage of the dawning comprehension of the spoken word and its meaning is quickly followed by the infant's attempt to repeat them, though it frequently happens that the sounds produced by the child, in its early attempts, have little resemblance to the real sound, hence the child passes through a stage where it appears to be manufacturing words of its own. For instance, Darwin mentions that one of his own children, at the age of 12 months, when he wanted food, began to utter the sound *mum*, instead of crying for it. Once this stage has been acquired the child rapidly passes to the production of words denoting ideas and objects, and at, or about, the 18th month, the child should begin to utter simple words intelligently; the subsequent acquisition of a vocabulary will depend, first, on the numbers of neurons possessed—the cerebral ament, for example, will seldom have anything but a very limited vocabulary—and second, on the environment. An individual trained through the primary, secondary or technical schools, and the university, will invariably possess a richer vocabulary than a child who leaves the primary school at the age of 12 or 13, because he is continually stimulating the conversion of cerebral neuroblasts into neu-

rons, and is thus constantly enriching the cerebral neuronie pattern. There are, of course, a few exceptions to this generality, but they simply prove the rule and the truth.

Correlation of the Above Phenomena with the Neuronie Pattern of the Cortex. It has been shown that at birth the cerebral cortex is in a plastic condition and that many of its cells, certainly those of the association areas, are in the non-functional neuroblastic stage. It has been further shown that the supra-granular pyramidal cells are those which, developmentally, lag behind, as do also many of the granular cells (Golgi Type II), particularly in the association areas. It consequently follows that the earliest attempts at speech must be largely through the neurons of the almost completely developed infra-granular cortex, and particularly in those areas, termed association areas, where so many incoming receptor impulses are stored up and commingled.

In the normal child the simple words spoken to it by the mother are received in the acoustic area, that is, the cortical area in the temporal lobe, known as the audito-sensory area, of both cerebral hemispheres. The constant exercise of this area converts the neuroblasts into neurons, and in due course the audito-sensory area becomes connected by myelinated association and other neurons with the final common effector area for the speech muscles, which is presumably Broca's area. The child thus repeats or echoes the sounds it hears and it has now reached that stage in the acquisition of speech already referred to as echolalia. As the neuronie education of the brain proceeds the audito-sensory area becomes linked up by short association neurons with the audito-psychic area and there commences the process of memory of the sounds heard.

Concurrently with these important changes in the auditory area, very similar developments are taking place in the visual cortex. Impulses of sight are first received in the visuo-sensory area, and then passed on, as the association neurons myelinate, to the visuo-psychic area, and as these areas become linked up with the auditory areas, the child commences to associate the sound with the object. Further neu-

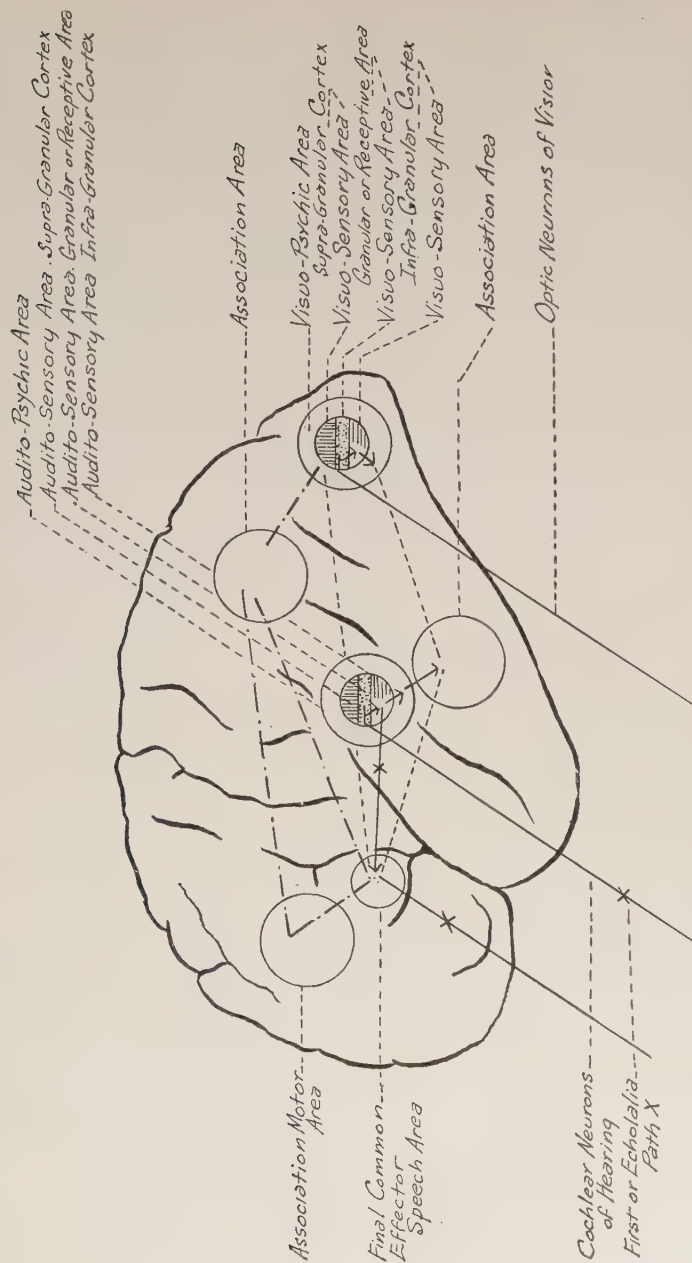


FIG. 113.—A diagram to illustrate the principles underlying the neuronic mechanism of the acquisition of speech and its loss by disease. See pages 406, 408, 412, 413.

ronic connections are then formed between the auditory and visual areas on the one hand, and an association area on the other. In this last area there is, as it were, a common fusion of the stored up impulses received through the auditory and visual areas and, as a natural consequence, the child begins to understand, and to utter the sound in correct reference to its meaning, that is, intelligence commences to dawn. With an extension of myelinated fibres between all the various areas concerned the child is now enabled to utter intelligible sounds and speech commences with a simple vocabulary.

In view of the almost universal misapprehension as to the phenomena attending the acquisition of speech it is important to note that there is nothing revolutionary in these views. They are all in strict accordance with well established physiological and neurological laws, and have repeatedly been set forth in this work. The natural acquisition of speech by the human infant conforms in all respects to the well established laws of "facilitation" and "forward direction" and to the "nature of the connection between neurons," that is, to the presence of a large number of internuncial neurons between the receptor and effector limbs of the arcs concerned.

Cerebellar cortical histology compels the conclusion that nerve impulses become arrested or stored up in the short internuncial neurons. Spinal cord histology proves that such neurons must be associated, and as the cerebral cortex is a combination of both it consequently follows that every word and phrase which is uttered implies that a certain number of cortical neurons have previously been charged with the impulses necessary for their production. When, therefore, it is said that "nothing but hopeless confusion can result from the mixture of brain cells and ideas" the neurological reply is that it is exactly this pernicious doctrine which is today responsible for so much error.

Correlation of the Vocabulary with the Numbers of Cortical Neurons. It is clear that modern neurological study compels the conclusion that ideas are merely words stored up in cortical neurons as a result of previous incoming impulses

of sound or sight, and in the case of the blind, of touch. No one can remember a word which he has never heard, nor is it always possible to remember a word which has only once been heard. The first proves, therefore, the truth of the doctrine that ideas or words result from a preliminary charging of appropriate neurons and the storing up of the impulses in the same or other neurons. That a word only once heard is not always remembered is but another example of the physiological law of facilitation, and here means that the neuron path concerned has not been sufficiently tracked and the sound has thus not become stored up in the appropriate neurons.

It is sometimes objected that there are not sufficient neurons in the cerebral cortex to store up all the words of the vocabulary of the educated man, particularly if he speaks or reads several languages besides his own. This is another of those errors so frequently mistaken for intelligent criticism. The word vocabulary of the ordinary man is very limited. At the best it does not exceed several thousand words, whereas, his neurons run into millions, quite apart from any mathematical commutations thereof. The vocabulary of Shakespeare, supposed by literary authorities to be the richest in the English language, did not exceed 20,000 words, but was in excess of that of Milton. The vocabulary of the ignorant is very limited, as is also the phraseology, and is largely restricted to those words concerned in the lowest of the animal instincts, because in such individuals, the supra-granular cortex is lacking in development, and consequently the ideas reflected by the speech are largely those associated with the animal functions of this layer of the brain. It is thus clear that notwithstanding the apparent largeness of the vocabulary of the educated man there is nothing to offset the view that that vocabulary is stored up in the cortical neurons. As Starling says, "There is probably no word, still less a collection of words, expressing an idea, which does not involve the activity of practically all parts of the cerebral cortex." It consequently follows that diagrams purporting to represent the speech

centre as being solely in Broca's convolution should disappear from medical textbooks.

Further Education of the Child's Cerebral Cortex. Having acquired the faculty of speech proper, that is, the utterance of simple words reflecting ideas, the child is next educated to read, and hence the faculty of the utterance of speech reflecting ideas is considerably increased. Printed letters are not to be regarded as signs of ideas, but as signs of sounds, hence the acquisition of the faculty of reading is merely speech conveyed by sight instead of sound. This implies an extension of the visual area of the cortex, by the myelination of suitable association neurons, into, presumably, the angular gyrus of the parietal lobe, that is, a portion of the cortex between the visual and auditory areas, and this, in its turn, becomes linked up with the visual, auditory, and other areas concerned in speech, and as all this implies the conversion of still more neuroblasts into neurons the child's intelligence grows accordingly.

With the copying of the printed letters, the child acquires the art of writing, and the portion of the cortex finally concerned is believed to be situated within the middle frontal convolution, but becomes linked up with all the other cortical areas involved in the acquisition of speech.

It is thus clear that the faculty of speech is a much more complex neuronc mechanism than its mere placing in Broca's area would lead one to suppose. It necessitates the presence of a very large number of neurons, and man alone possesses such a number of cortical neurons, and is, consequently, the only animal to speak. But the microcephalic idiot does not speak, nor does the normal child speak unless it is laboriously educated thereto, which proves that speech results from first, the retention within the cortical neurons of previous incoming impulses of sound and sight, and second, their storage within appropriate cortical neurons. Speech thus involves a very intricate neuronc association of many parts of the cerebral cortex, and it follows that individuals display many differences according to the number of neurons possessed, the final stage

of development attained, and the nature of their associations. If a child possess, at birth, an insufficiency of cortical neurons or their potentialities—neuroblasts—he will either become a microcephalic idiot, quite incapable of speech, or he will be very late in acquiring the properties of speech and will certainly be an ament of some degree. Late acquisition of speech by a child is one of the most certain clinical signs of commencing amentia, which again shows that speech involves many neurons.

Notwithstanding the much greater complexity of the neuronie connections concerned in the production of speech, there can be no doubt that the physiological neuronie basis is the same for speech as it is for any other nerve function, that is, it is compounded of the elements of the neuronie arc and is often reflex in its manifestation. Language, as normally employed, is very largely purely reflex, or at any rate, automatic, and the significance of what is spoken is often but feebly appreciated by the speaker. Examples are quite common in which the mechanism of language is employed in a purely mechanical manner, just as are many other nerve phenomena. Children often learn a large portion of their lessons in a reflex unintelligent way, but if the words be repeated in correct sequence such repetition is mistaken for intelligence. Many word complexes, which are frequently repeated, are often gone through in a purely mechanical manner, whilst the individual repeating them is thinking of something else. In the ill-educated and the unintelligent, in fact, in the majority of persons, the word vocabulary in common use is very limited, and the phrase vocabulary is both extremely limited, remarkably stereotyped, and in many cases quite automatically employed. In well educated persons, on the other hand, the word and phrase vocabularies, though equally stereotyped, are much more extensive in range. The voluntary employment of the language mechanism is attended by greater executive difficulties than is the reflexly induced and automatically performed mode just indicated and is at times involuntarily incited, to the detriment of the performance

by emotional disturbances. By its proper use, language is the servant, and the necessary servant of thought. By its abuse it becomes the supplanter of thought. It thus follows that an extensive vocabulary, indicative of ideas, is the surest indication of intelligence. An outflow of words, on the other hand, is only too frequently the mark of the ament.

Brain Cells and Ideas. It is thus obvious that so far from nothing but hopeless confusion arising from "the mixture of brain cells and ideas" it is this very view which is alone correct and alone complies with the ascertained facts relative to the acquisition of speech, its mode of use in every day life, and its temporary and permanent loss. No other view but that of a multiplicity of cortical neurons storing up auditory and verbal images can satisfactorily explain even the most rudimentary facts relative to speech. The view, too long held in Medicine, that speech results from some restricted portion of the cortex, such as Broca's area, is utterly subversive of the truth, and is still responsible for much of the confusion. So long as that opinion is held, just so long will it be impossible to understand the most elementary phenomena of aphasia.

It is not, on the other hand, to be supposed that the view here advocated, that speech results from a multiplicity of neurons inter-related through the cerebral cortex, with specialised functional areas at certain places, dismisses all the difficulties. It does not. It merely gives a correct starting point, instead of an incorrect one, for the study of speech, but that in itself is an enormous gain. Difficulties still remain. For example, almost all clinical evidence goes to show that gross macroscopic lesions producing aphasia in right handed persons, are situated in the left cerebral cortex. It is certain that during the acquisition of speech in the infant the speech sounds are received by the temporal lobes of both sides, whilst the visual images to be correlated with those sounds are similarly received by both visual occipital regions. How then comes it that almost all aphasic lesions are found only on the left side, and what is the right cerebral hemisphere

doing as regards speech? Neurologically it is a well established fact that all portions of one neopallium are connected to every portion of the opposite neopallium by commissural axons passing through the corpus callosum, and it is, as yet, impossible to explain the path of cortical neuronie impulses concerned in speech from the one hemisphere to the other. It is unreasonable to assume that nerve impulses are restricted

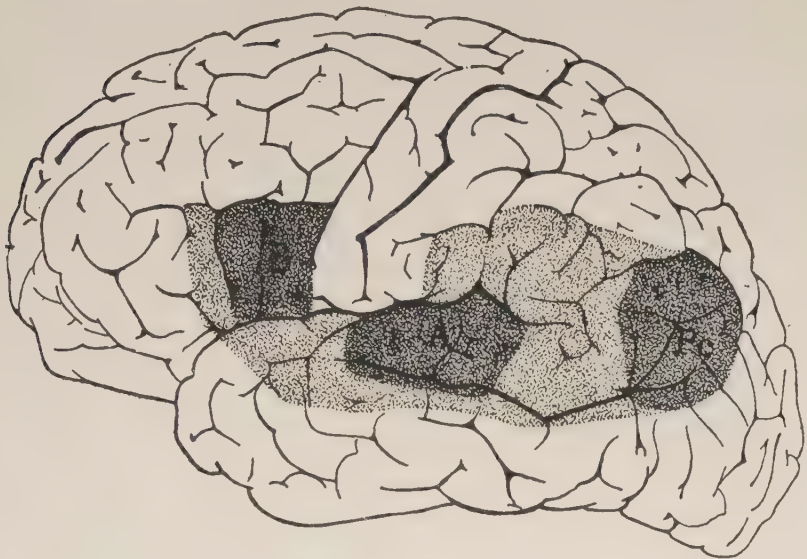


FIG. 114.—*A*, Wernicke's centre, for auditory verbal images; *B*, Broca's centre, for motor verbal images; *Pc*, centre for visual verbal images. (From: Luciani, "Human Physiology.")

to the one cerebral hemisphere, and yet most aphasic lesions are limited to the one side. The parts played by the associational systems of the brain in the production of speech are more easily understood and appear to conform with the evolutionary law that such systems precede the commissural, but the function played by these last is certainly not as clear.

The Aphasias. It is not proposed here to embark on either a clinical or neurological discussion of the aphasias. Some general propositions, which inevitably result from a neurological and histological study of the brain may, however, be set forth.

It is quite futile to endeavour to explain the phenomena of mind, that is speech reflecting ideas, without constant reference to the cortical neurons. As these differ very considerably in different individuals, both in their numbers, state of development, durability, and so on, and as the stimuli, that is spoken sounds and printed sounds, to which the individual has been subjected also differ, it is never to be expected that the same lesion occurring in any two persons will produce exactly the same aphasic phenomena. The clinician, as a general rule, only studies the exact site of the lesion, and if he cannot see the lesion he too readily assumes there is no lesion. It is not sufficient to study only the site of the lesion. There is the depth of the cortex, the relative thickness of its supra-granular and infra-granular layers, and the numbers of neurons to be considered as well as the site. It is not to be assumed that a lesion, even though macroscopic and occurring in exactly the same place, will produce the same aphasic effects in the low or high grade ament and the man of genius. The latter possesses far more neurons and both his main cortical layers are thicker than in the ament. Consequently the doctrine that speech involves a multiplicity of neurons also denotes that the same speech phenomena will never be altered in exactly the same way in any two individuals, even though the same lesion be present in both, and this, the main clinical features apart, is only too obvious a truth.

That aphasia may result from other than purely macroscopic lesions is also obvious, as any toxæmic or functional bodily disorder may so impair the chemical composition of the neuron, as to destroy its powers as a functional unit. The dementia of old age impairs both the vocabulary and the intelligence, because brain cells, once functional, are gradually destroyed, and important links in the neuron chain are taken out, though it is quite certain that such neuron loss will never be detected by the naked eye at a perfunctory post-mortem examination.

It is not to be assumed that these remarks are intended to discredit the excellent work already accomplished by many

distinguished authorities on aphasia. It will, however, be generally found that the best authorities hold these views. Marie's are too well known to need recapitulation, whilst Dr. Kinnear Wilson has also stated, though the remark does not seem to be as well known as it should be, that "neglect of the anatomical and physiological basis of speech is largely responsible for the present confusion."

CHAPTER XXXI

THE STRUCTURE OF THE WHITE MATTER OF THE CEREBRAL HEMISPHERES

General Arrangement of the White Cerebral Matter. The cerebral hemispheres are composed of white and grey substance, that is, of the dendrons, cell-bodies and axons of neurons. The white medullary centre of the cerebral hemisphere underlies the grey cortex and separates it from the lateral ventricle and striate body.

The *white matter* is exclusively composed of medullated axons arranged in flattened bundles, separated and supported by neuroglia. It pervades and forms almost the whole of the interior of each cerebral hemisphere, where it constitutes the *medullary centre*. White matter is also found in the cerebral cortex, where it occurs in the form of extremely thin white lines parallel to the cortical surface and variously known as fibre laminæ, lines of Baillarger and the stria of Gennari. It is also found in bundles running at right angles to the cortical surface. These bundles consist of medullated axons passing into, or out of, the cerebral cortex from the medullary centre, and becoming continuous with the fibre laminæ. They separate the nerve cells of the cortex into columnar groups and thus give to the cortex a radial striation. Many of these radial bundles are the axons of the polymorphic and pyramidal cells of the cortex. They form the association, commissural and projection fibres to be presently described.

Embedded within the white medullary centre are certain detached portions of grey matter, which occur chiefly in the vicinity of the bases of the cerebral hemispheres, and are hence termed *basal ganglia*.

The medullated axons, which, in their many millions, form

the medullary centres of the cerebral hemispheres are the axons of neurons which have their cell-bodies located, chiefly, in the polymorphic and pyramidal cell layers of the cerebral cortex and the thalamus, and are divided into three great groups, projection fibres, commissural fibres, and association fibres.

Projection Fibres. Projection fibres are the axons of long-axoned neurons which convey impulses from, or to, the cerebral cortex. There are, therefore, two groups; those which arise in *cells of the cerebral cortex* and pass thence to parts outside the telencephalon; and those which arise in *parts outside* the telencephalon and pass into it, that is to say, the projection fibres of the neopallium are both receptor (corticipetal) and effector (corticifugal) in character.

The Receptor (Corticipetal) Projection Systems. The receptor (corticipetal) projection systems comprise (1) the *optic radiation*, which arises in the pulvinar of the thalamus and lateral geniculate body, and terminates in the visual cortex, where its fibres form the stria of Gennari. (2) The *auditory radiation*, which arises in the medial geniculate body, and terminates in the auditory cortex. (3) The *thalamic radiation* which unites the lateral nucleus of the thalamus with various parts of the cortex, and thus forms the ventral, frontal, and parietal stalks of the thalamus. Included in the last mentioned are the receptor neurons passing to the somæsthetic cortex in the posterior central gyrus.

The Effector (Corticifugal) Projection Systems. The neurons of these systems convey impulses from the cortex to the thalamus, brain stem and spinal cord, and the medullated axons arise in pyramidal cortical cells. The most important of these are the *cortico-spinal* and *cortico-bulbar tracts*, which together form the great motor or pyramidal system, and have been fully described. The *cerebro-ponto-cerebellar tracts* connecting the cerebrum with the cerebellum, by way of synaptic junctions in the nuclei pontis have also been described. Another important system of effector projection fibres is the *cortico-thalamic*, whose neurons run from the cerebral cortex

to the thalamus, and thus bring the thalamus and other basal ganglia under the control of the cortex. Still other effector projection fibres are found in the optic radiation and possibly in the auditory radiation, whilst a *cortico-rubral tract* is described as passing from the frontal lobe to the red nucleus. No projection connections appear to exist between the cortex and the striate body, which is thus controlled either indirectly from the cortex through the thalamus, or by collateral branches from the cortico-spinal system or both.

Projection Systems of the Archipallium. Amongst the projection systems of the unimportant archipallium or smell brain may be mentioned the *lateral olfactory stria*, which conveys olfactory impulses from the olfactory bulb to the pyriform area; the *fornix*, whose fibres arise in the hippocampus and, entering the diencephalon, terminate partly in the mammillary body, and partly in the tegmentum of the brain stem; and the *frontal olfactory projection tract* which arises in the olfactory peduncle and the lateral olfactory gyrus and terminates in the pons and medulla.

The Association Systems. The association systems comprise neurons which connect together different portions of the cerebral cortex of the same side. All parts of the cerebral cortex are directly or indirectly connected with all other parts by these association fibres, so that no one region of the cortex can be considered as being the exclusive seat of any particular mental function. Mentality involves the whole and any impairment of a part necessarily impairs the whole. Association fibres are divided, according to their length, into two great groups, short and long.

The *short association fibres* are of two kinds, intra-cortical and sub-cortical. Of these the *intra-cortical* occupy the deepest part of the grey cerebral cortex, and link together adjacent gyri. The *sub-cortical* lie immediately subjacent to the grey cerebral cortex, between it and the white medullary centre of the hemisphere, and link together adjacent gyri. The short association systems seem to play an important part in the phenomena of mind, and do not myelinate until such time

after birth as education and the exercise of the intellect have stimulated different parts of the cerebral cortex to act in harmony. They thus play an important rôle in the acquisition of speech.

The *long association fibres* form well-marked bundles which run for considerable distances within the white medullary centre of the cerebral hemisphere, and unite together widely distant portions of cortex. They are thus of considerable size and most of them can be demonstrated by dissection.

The *uncinate fasciculus* connects the orbital gyri of the frontal lobe with the anterior portion of the temporal lobe.

The *inferior longitudinal fasciculus* runs through the whole length of the temporal and occipital lobes. It connects the occipital pole, cuneus, and other parts of the occipital lobe with the temporal cortex, and would thus appear to play some part in the cerebral synchronisation of visual and auditory impulses.

The *superior longitudinal fasciculus* connects together many of the parts lying on the lateral surface of the brain, chiefly the frontal region with the occipital and temporal. In its passage between these areas, the superior longitudinal fasciculus sweeps over the insula to the occipital end of the lateral fissure of Sylvius, where it turns round the putamen of the lentiform nucleus, and there divides into two parts, one passing to the occipital region, and the other to the temporal region.

The *superior occipito-frontal fasciculus* runs in a sagittal direction immediately above the lateral ventricle, on the medial side of the corona radiata and in intimate relation to the caudate nucleus. Its connections and functions are not understood.

All the foregoing are association systems of the neopallium. The *cingulum* is an arched bundle, which partly encircles the corpus callosum and belongs to the archipallium.

The Commissural Systems. Commissural fibres are those which connect together the grey cerebral cortices of the two cerebral hemispheres. They are arranged in three chief

groups, one, the corpus callosum, belonging to the neopallium, and two others, the anterior and hippocampal commissures, belonging to the unimportant archipallium.

The neopallial *corpus callosum* is the largest and most important of the commissures, and its radiation contributes largely to the bulk of the semi-oval centre of the cerebral white matter. The axons which compose it arise in the cells of various parts of the cerebral cortex. They pass thence through the callosal radiation and converge on the corpus callosum, in which they cross the middle line. In the opposite cerebral hemisphere they again radiate out in the callosal radiation and terminate in the cerebral cortex of the opposite side by establishing synaptic junctions with its myriads of neurons. Some cortical areas are better supplied with commissural systems than others, few, if any, for example, being associated with the visual cortex. It is to be further noted that all regions of the cortex do not receive an equal number of callosal commissural fibres, and that such fibres do not connect together symmetrical portions of cerebral cortex. Each callosal fibre arises in one or other of three ways, as the axon of a pyramidal or polymorphic cortical cell, or as the collateral branch of an association or projection fibre.

Similarity Between the Spinal Cord and the Cerebral Hemisphere. A study of the spinal cord and the cerebral hemisphere thus shows that in both portions of the neuraxis the mode of junction between conducting systems of neurons is exactly the same, and is by means of associational and commissural neurons. These are, however, very much more numerous in the brain than in the spinal cord, and further the brain is provided with enormous numbers of granular cells. The cerebellum, on the other hand, contains innumerable granular cells but no association or commissural systems. The brain is thus composed of both the spinal cord and cerebellar types of junctional nerve tissue and it is on this tissue that attention should be concentrated in the study of mind and its disorders.

Medullation and Growth of Cerebral Neurons. It is

extremely important to remember, if the functional working of the nervous system is to be understood, that the neuron passes developmentally through several successive stages. There is the embryological undifferentiated nerve cell, the neuroblast, the non-medullated neuron, and the medullated neuron. Differently expressed the nervous system is originally composed of grey (non-medullated) nerve elements only, and apparently some of its older phylogenetic parts, such as certain portions of the autonomic nervous system, function both normally and well in a non-myelinated condition. To the higher portions of the nervous system, particularly the brain, where many millions of neurons are in the closest anatomical juxtaposition, myelination is absolutely essential to function, and this conversion from the primitive grey condition to white, as seen in the medullary centres of the brain, is brought about by the development of myelin in the sheaths of the axons. This myelin consists of fatty substances and a small amount of watery fluid. If the "grey" neuroblasts of the brain do not undergo this developmental transference from grey to white there can be no function. The earlier observations of Donaldson, as well as the later ones of Flechsig, all confirm the very great importance of cerebral myelination to function, and further prove the fact that the process begins at different periods of pre- and post-natal life, and may continue in some individuals up to, and beyond, the fortieth year of life, particularly in those who follow mental occupations rather than purely manual. In others, on the other hand, it may never attain even a normal development, and mentality becomes correspondingly lowered.

Brain Growth. Increase in brain size after birth is almost entirely dependent on this process of gradual myelination of cerebral axons. Calculation shows that the absolute mass of the medullary substance is the chief source of increase in weight during this period. The weight increase in the nerve elements proper is due to the enlargement and subsequent myelination of those neurons which at birth are small, or in a neuroblastic condition, and not to the addition of any new

neurons, because no new neurons are formed after birth. Postnatal brain growth is, therefore, partly composed of the conversion of neuroblasts into neurons, and of the myelination of the axons of such neurons, without which they cannot function; and partly of an increase in the non-nervous supporting tissue, the neuroglia. If the development of these two factors proceed unequally, there may result the large heavy brain of the imbecile, that is, too much fibrous tissue and too few neurons.

Quite apart from the conversion of neuroblasts into neurons, a process which is essential to normal mentality, there is another factor to be considered, and that is, the physiological connections between these innumerable cortical neurons. It is obvious that the two processes, namely, conversion of a sufficiency of neuroblasts into neurons, and the establishment of a correct physiological connection between them, that is, their conversion into functional neuronie cortical arcs, do not always proceed either normally, or *pari passu*, in which case an altered mentality, even to insanity, may result. The extent and thickness of the cerebral cortex is, therefore, dependent on the number of its fully developed neurons, whilst the mass and weight of the medullary substance is due to correct myelination of the innumerable association, commissural, and projection axons.

Importance of a Study of the Thickness of the Cerebral Cortex. That the thickness of the cerebral cortex is diminished in aments, many criminals, and some of the insane, is well established as the result of microscopic measurement of the cortex by Donaldson, Wilson, Major, Bucknill and Tuke, Cionini, and more recently by Bolton and Watson. For example, in the brains of 26 normal individuals examined by Conti, Franceschi, and Donaldson, the average cortical thickness was 2.49mm., whereas in 35 insane examined by Bucknill and Tuke it was only 1.88mm., and this earlier work has been fully confirmed and amplified by Bolton. From all this it necessarily follows that normal cerebral function, that is, mentality, depends on certain very important factors, namely:

1. A sufficiency of fully developed neurons and a relative absence of neuroblasts.
2. A correct physiological connection between these neurons.
3. An adequate myelination of the axons in those neurons whose axons should myelinate.
4. An adequate supply of oxygen to the neurons.
5. An absence of bodily poisons, whether artificially introduced, or as the result of bodily toxæmias.
6. A normal durability of the neuronie tissue. In some strains of enfeebled heredity the neuronie tissue is also enfeebled, and hence dementia præcox may occur at an early age.

Different lines of cortical investigation thus show that in every human individual the number of potential cortical nerve elements (neuroblasts) which might possibly develop into functional entities (neurons) is always in excess of those which actually do so. This fact explains in part the different histological appearances of different brains, that is, as regards thickness of cortex and numbers of neurons, and also explains differences between different parts of the same brain. This occasional lack of conversion of neuroblasts into neurons is particularly noticeable in the visuo-sensory and audito-sensory portions of the cortex where the individual has been blind or dumb. Under these conditions the granular and supra-granular layers of the cortex are always thinner than usual. Something of this same developmental failure also takes place in the brains of congenital aments and of many demented.

The Corpus Callosum. The corpus callosum is the great transverse commissure which passes between, and connects together, the medial surfaces of the two cerebral hemispheres throughout nearly one-half of their fronto-occipital extent. The greater portion of it is concealed within the cerebral hemisphere, and only a minor part lies free within the depths of the longitudinal fissure of the cerebrum.

The corpus callosum is situated nearer the frontal pole than the occipital pole, and is about 10 cm. long. It is highly arched in the fronto-occipital direction, and presents for examination, a convex surface, a concave surface, a frontal extrem-

ity or genu with a rostrum, a trunk, and an occipital extremity or splenium.

The *convex surface* of the trunk of the corpus callosum forms the floor of the longitudinal fissure of the brain in the median line, and the sulcus of the corpus callosum on either side of that line. At its occipital end it is in contact, in the median line, with the falx cerebri.

This surface of the trunk of the corpus callosum is covered by an extremely thin layer of grey substance which is continuous, through the sulcus of the corpus callosum, with the grey cortex of the medial surface of the hemisphere. Embedded in this grey substance are two pairs of delicate fronto-occipital strands of white substance, one pair lying on either side of the median line, and termed the medial and lateral longitudinal striæ.

This thin sheet of grey substance, with its two pairs of longitudinal striæ, represents the aborted convolution known as the *supra-callosal gyrus*. The grey substance of which it is composed is so thin as to be translucent; hence the longitudinal striæ, together with the transversely directed medullated nerve fibres of which the corpus callosum is composed, can be seen through it. At the splenium of the corpus callosum, the supra-callosal gyrus, with its contained medial and lateral longitudinal striæ, becomes continuous with the dentate fascia. At the genu of the corpus callosum, the grey substance of the supra-callosal gyrus and the longitudinal striæ are continued into a narrow cortical strip, which lies on the medial surface of the hemisphere close to the genu of the corpus callosum, and is termed the *subcallosal gyrus*. The fibres of this gyrus become continuous with the medial stria of the olfactory tract.

The *concave surface* of the trunk of the corpus callosum is, in the *median line*, attached to the septum pellucidum, and the body of the fornix. On *either side* of the median line the concave surface is, for the most part, free and lined by epithelium, and forms the roof of part of the lateral ventricle.

The *frontal end* of the corpus callosum is termed the *genu*, and is folded upon itself. It becomes continuous with the

attenuated *rostrum*, which, in its turn, becomes continuous with the *lamina rostralis*.

The *trunk* of the corpus callosum extends from the genu to the splenium, and is thinner than either of those parts.

The *splenium* is the greatly thickened occipital extremity of the corpus callosum. It lies close to the midbrain, and extends as far as the most cranially projecting point of the cerebellum.

Structure of the Corpus Callosum. The corpus callosum is composed of medullated nerve fibres which pass transversely through it from all parts of the neopallial cerebral cortex of one side to that of the other. This radiation of fibres forms the *callosal radiation*, and its fibres intersect, in the medullary centre of the hemisphere, those of the corona radiata, that is, the fibres passing between the cerebral cortex and the internal capsule.

Those fibres of the callosal radiation which pass through the genu sweep round into the prefrontal region and form the *frontal part* of the radiation.

Those fibres of the callosal radiation which pass through the splenium are termed the *occipital part* of the radiation, and they curve abruptly into the occipital region, and produce in the medial wall of the posterior horn of the lateral ventricle the elevation known as the *bulb of the occipital horn*.

Passing through the trunk of the corpus callosum are many axons proceeding to, and from, the parietal and temporal regions of the neopallial cortex, and it is these which produce the transverse striation seen on the upper surface of the corpus callosum. Some of these fibres are occasionally termed the *tapetum*.

CHAPTER XXXII

THE VENTRICULAR SYSTEM OF THE CENTRAL NERVOUS SYSTEM

Development of the Ventricular System. The central nervous system is developed from the neural canal, which is a hollow structure. It consequently follows that the adult central nervous system is also hollow, and the original cavity of the neural tube persists as the ventricular system of the adult.

It has already been shown that in the early embryo the encephalon or brain consists of three hollow vesicles, termed the rhombencephalon or hindbrain, the mesencephalon or midbrain, and the prosencephalon or forebrain, and the parts developed from each can easily be recognised in the adult brain and have already been set forth. (See page 52.)

The primitive cavity of the *hindbrain* expands to form the fourth ventricle, which is directly continuous with the central canal of the spinal cord, as well as communicating with the third ventricle and the subarachnoid spaces.

The primitive cavity of the *midbrain* persists as the tubular communication—the cerebral aqueduct of Sylvius—between the fourth and third ventricles.

The walls of the *prosencephalon* undergo great changes. Its frontal part, or *telencephalon*, expands laterally as two hollow vesicles, the cavities of which become the lateral ventricles, whilst the surrounding walls become greatly thickened to form the cerebral hemispheres and their commissures. The cavity of the *diencephalon* forms the greater part of the third ventricle, which communicates with the lateral ventricles by means of the interventricular foramen of Monro, and with the fourth ventricle by means of the cerebral aqueduct of Sylvius.

It is thus obvious that the whole of the central nervous system of man is a hollow structure.

Advantages of the Hollow Type of Central Nervous System. In all invertebrates the central nervous system is solid and is constructed on a totally different plan from that of vertebrates. But the form of the nervous system, whether solid or hollow, is always strictly correlated with the behaviour of the animal possessing it.

The *solid type of nervous system* allows of little or no alteration or additions thereto, and consequently the behaviour of animals possessing this type is invariable or innate, and the animal responds to its environment in a mechanical and invariable manner, and is unable to adapt itself to unusual conditions.

The *hollow type*, on the other hand, readily permits of neuron additions being made thereto, because the grey matter can now be brought to the surface. (See page 172.) Consequently very considerable additions occur in the numbers of neurons, and the animal's behaviour passes from the invariable or innate to the variable or individually modifiable. "In the analysis of behaviour and the related neurological mechanisms the distinction between the innate and the individually acquired factors must always be kept clearly in mind. The failure to do so, and also the failure to distinguish between these two factors and the acquired automatisms is responsible for much confusion in the current discussions of instinct." (Herrick.)

A second, though not such a significant advantage as that last mentioned, is that the hollow type of central nervous system permits of the whole system being suspended, as it were, in a species of water bath, and it is thus protected still further against injuries.

The Lateral Ventricles. The lateral ventricles, two in number, are the cavities in the interior of the cerebral hemispheres. Each lateral ventricle is continuous with its fellow and with the third ventricle by means of the interventricular foramen of Monro, and is lined throughout by ependyma,

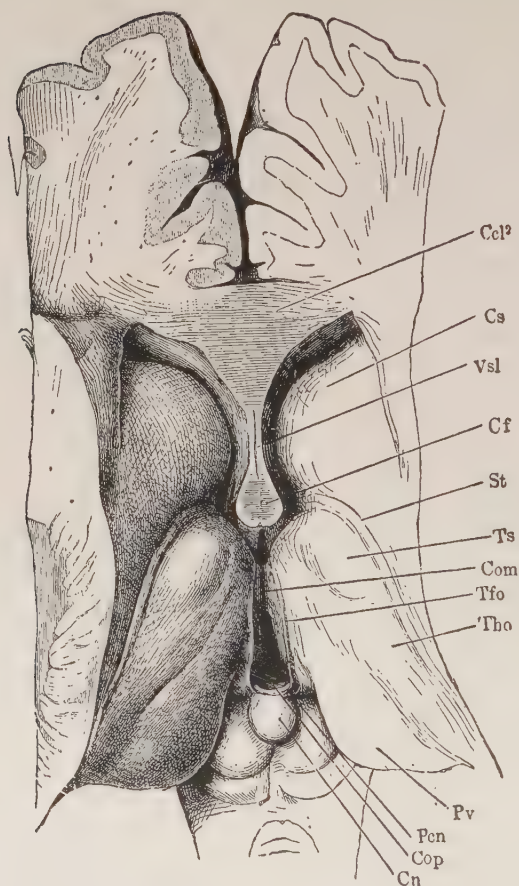


FIG. 115.—View from above of third ventricle and part of the lateral ventricles. (Henle.) The brain has been sliced horizontally immediately below the corpus callosum, and the fornix and velum interpositum have been removed. *Tho*, thalamus opticus; *Ts*, its anterior tubercle; *Pv*, pulvinar; *Com*, middle commissure stretching between the two optic thalami across middle of third ventricle; *Cf*, columns of fornix; *Cn*, pineal gland projecting downwards and backwards between superior corpora quadrigemina; *St*, stria terminalis; *Cs*, nucleus caudatus of corpus striatum; *Vsl*, ventricle of septum lucidum; *Ccl*² section of genu of corpus callosum; *Pcn*, pineal peduncle; *Tfo*, pineal strial; *Cop*, posterior commissure. (From: Luciani, "Human Physiology.")

which is continuous with the ependymal lining of the cerebral ventricular system.

Each lateral ventricle is a highly irregular cavity, which presents for examination a central part or body and three horns, frontal, occipital, and temporal.

The *frontal horn* lies frontal to the interventricular foramen of Monro, and extends into the frontal lobe. On its lateral side may be seen part of the caudate nucleus, whilst its vertical medial wall is formed by the septum pellucidum which separates it from its fellow of the opposite side.

The *central part* or *body* extends from the interventricular foramen of Monro to about opposite the splenium of the corpus callosum. Within its floor may be seen parts of the caudate nucleus, the thalamus, chorioid plexus and fornix.

The *occipital horn* curves into the occipital lobe. On its medial wall may be seen the bulb of the *occipital horn*, produced by some of the commissural fibres of the corpus callosum, and the *calcar avis* produced by the infolding of the cortex around part of the calcarine fissure.

The *temporal horn* sweeps round into the temporal lobe. Within its floor may be seen the *collateral eminence*, produced by the fissure of that name, the *hippocampus*, and parts of the *chorioid plexus* and the *fornix*.

Cerebrospinal Fluid. The whole of the ventricular system of the brain and of the central canal of the spinal cord is filled with fluid—the cerebrospinal fluid. This fluid is secreted from the blood vessels of the chorioid plexuses within the ventricles, and it is not improbable that its formation is due to an active secretion on the part of the epithelial cells covering these plexuses. The fluid so secreted pervades the whole of the ventricular system of the brain and central canal of the spinal cord, and passes out through the foramina in the roof of the fourth ventricle into the subarachnoid spaces, whence it is absorbed back again into the circulatory system through the cerebral veins. It thus follows that the whole of the central nervous system is suspended within a species of water-bath, composed of cerebrospinal fluid, which is constantly being

secreted and as constantly removed. Whatever other functions may be ascribed to the cerebrospinal fluid, it is certain that a principal one is protection to the delicate substance of the brain and spinal cord. Should the foramina within the roof of the fourth ventricle be occluded at birth, then the cerebrospinal fluid, which is being constantly secreted within the ventricles, can no longer escape and hydrocephalus results. The amount of cerebrospinal fluid normally present is not definitely known, but is usually believed to be about 60 to 80cc. Its rate of normal secretion may be gauged from the fact that in fracture of the base of the skull it has been found to drain off steadily at the rate of 200cc., or more, per day.

CHAPTER XXXIII

THE BASAL GANGLIA AND THE THALAMO-STRIATE BRAIN

The Basal Ganglia. The basal ganglia are certain masses of grey matter, more or less completely embedded in the white medullary substance of the cerebral hemisphere, and are developed in its wall. These are as follows:

The striate body.

a. The caudate nucleus or intraventricular part.

b. The lentiform nucleus or extraventricular part.

The claustrum.

The amygdaloid nucleus.

The Striate Body. The striate body is an important evolutionary structure, which is situated near the base of each cerebral hemisphere lateral to the thalamus. It consists of a large mass of grey cerebral substance embedded in the white medullary substance, and receives its name because in certain sections it appears to be streaked or striated by certain laminæ of white matter. It is in large part extra-ventricular, but a smaller part is visible in the frontal horn of the lateral ventricle. The *intraventricular* portion is the caudate nucleus, and the *extraventricular* part is the lentiform or lenticular nucleus.

The Caudate Nucleus. The caudate nucleus is a pyriform, highly arched mass of grey matter, which bulges into the lateral ventricle, and presents for examination a thick swollen extremity or head, and an attenuated tail.

The *head of the caudate nucleus* forms a prominent swelling in the frontal horn of the lateral ventricle, with which it as nearly as possible coincides. In the region of the anterior perforated substance it gains the surface, and its grey matter becomes continuous with that of the cerebral cortex.

The *tail of the caudate nucleus* is the occipital prolongation of the head. It sweeps round into the roof of the temporal

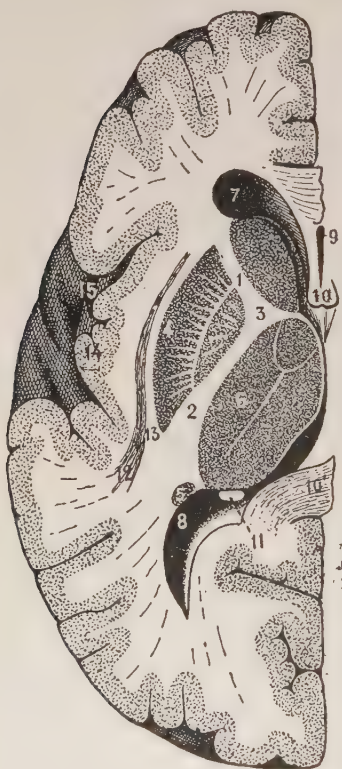


FIG. 116.—Horizontal section of left hemisphere. (Flechsig.) 1, anterior; 2, posterior limb; 3, genu of internal capsule; 4, nucleus lenticularis; 5, nucleus caudatus; 6, optic thalamus; 7, anterior horn of lateral ventricle; 8, its posterior or occipital horn; 9, septum lucidum and its central cavity; 10, 11, fornix; 10', corpus callosum; 12, claustrum; 13, external capsule; 14, insula; 15, Sylvian fissure. (From: Luciani, "Human Physiology.")

horn of the ventricle, in which it terminates by joining the amygdaloid nucleus. The caudate nucleus thus presents a free, intraventricular surface, covered by a continuation of the epithelial chorioid lamina, and a deep surface embedded in the white medullary substance of the hemisphere, and mostly in contact with the internal capsule. On account of its highly arched form, it follows that in horizontal sections caudal to a particular level, the caudate nucleus is always seen cut in two parts, as is also the case in frontal sections made on the occipital side of the amygdaloid nucleus.

The Lentiform or Lenticular Nucleus. The lentiform or lenticular nucleus is that part of the striate body which lies lateral to the caudate nucleus, and is, for the most part, embedded in the white medullary centre of the cerebral hemisphere.

As seen in *horizontal section* the lentiform nucleus assumes the form of a biconvex lens, the *lateral* surface of which corresponds, in point of extent, with the insula, from which it is separated by an unnamed strand of white matter, the claustrum, and the external capsule. The *medial* surface bulges medially, reaching its maximum convexity

opposite the terminal stria, or the interval between the caudate nucleus and the thalamus, from both of which it is separated by the internal capsule. The medial surface of the lentiform nucleus does not extend so far frontally or occipitally as the caudate nucleus, and is, therefore shorter than that structure.

As seen in *frontal section* the lentiform nucleus presents different appearances at different levels; thus if a frontal section be made through the *most frontal portion* of the nucleus, it is seen to be crescentic or semilunar, continuous below with the head of the caudate nucleus, and elsewhere connected to it by some strands of grey matter, which cross the internal capsule, and give, to the two structures, that striate appearance whence the name striate body is derived. In the region of the anterior perforated substance, both portions of the striate body reach the surface and become continuous with the cerebral cortex.

If a frontal section be made across the lentiform nucleus *through the anterior commissure*, it is seen to be triangular or wedge-shaped, the base or lateral surface of the triangular mass being turned towards the insula, from which it is separated by the external capsule, the claustrum, and an unnamed



FIG. 117.—Thalamencephalon and its relations. Frontal section through grey commissure. (Testut.) *a*, frontal portion of lateral ventricle; *b*, its inferior horn; *c*, third ventricle; *d*, Sylvian fissure; *e*, optic tract; *f*, gyrus hippocampi. 1, lamina medullaris interna of optic thalamus; 2, lamina medullaris externa; 3, internal; 4, external; 5, superior nucleus of optic thalamus; 6, caudate nucleus; 6', its lower end; 7, 7', lenticular nucleus; 8, claustrum; 9, external capsule; 10, internal capsule; 11, pes pedunculi; 12, substantia nigra; 13, stratum dorsale of regio subthalamica; 14, zona incerta; 15, nucleus of Luys; 16, anterior end of red nucleus; 17, great commissure. (From: Luciani, "Human Physiology.")

strand of white matter. The dorsomedial surface is oblique, and is in contact with the internal capsule, whilst the third surface is directed towards the base of the brain.

Sections through the lentiform nucleus also show that it is divided, by means of two vertical strands of white matter, termed the lateral and medial medullary laminæ, into three zones, the lateral and larger of which is known as the *putamen*, whilst the two medial together constitute the *globus pallidus*. This differentiation between the putamen and the globus pallidus is of considerable evolutionary and clinical significance, inasmuch as the globus pallidus is primordial in character, and the putamen is a more recent addition and has a somewhat different function.

The Claustrum. The claustrum is a thin, vertical sheet of grey matter embedded in the white medullary centre of the cerebral hemisphere, between the lentiform nucleus on its medial side, and the grey cortex of the insula on its lateral side. From the former the claustrum is separated by the external capsule, and from the latter by an unnamed strand of white matter. When traced *upwards* the claustrum gradually becomes thinner, and finally disappears, but when traced *downwards* it becomes thicker, and at the base of the brain comes to the surface at the anterior perforated substance, at which spot it becomes continuous with the grey cortex.

The Amygdaloid Nucleus. The amygdaloid nucleus is a round mass of grey matter situated in the piriform area of the temporal lobe, which appears upon the surface at the lateral extremity of the anterior perforated substance. The grey matter of which the nucleus is composed is directly continuous with the tail of the caudate nucleus, with the putamen of the lentiform nucleus, and with the grey matter of the cortex cerebri.

Morphology of the Basal Ganglia. The globus pallidus appears to be the representative in the mammalian brain of the striate body of lower forms, such as the shark. The greater part of the caudate nucleus, the putamen, the claustrum, and

the amygdaloid nucleus are, on the other hand, neopallial derivatives of much later evolution.

The Thalamo-Striate Brain. By the thalamo-striate brain is meant the subcortical receptor thalamus and the effector striate body. In many of the lower animals, such as fish and reptiles, where cerebral hemispheres are not present, these structures, or their primordial forerunners, form the only brain of control which the animal possesses. In the mammals and man in particular a real endbrain has been added beyond the thalamo-striate brain, and is represented by the neopallial cerebral hemispheres. To these have been transferred, by the process of telecephalisation previously referred to, many of the original functions of the thalamo-striate brain, together with the control over those functions. Should, however, the nerve impulses be diverted to the more primitive pathway, there will be a display of somewhat uncontrolled emotional reflexes, because the controlling cerebral cortex is now largely cut out of the nerve circuit. As the thalamic portion of the thalamo-striate brain is a diencephalic derivative and has been considered therewith, there only remains the striate body, which is a telencephalic formation.

Evolution of the Striate Body. The striate body is a structure which has undergone much evolutionary change, and as

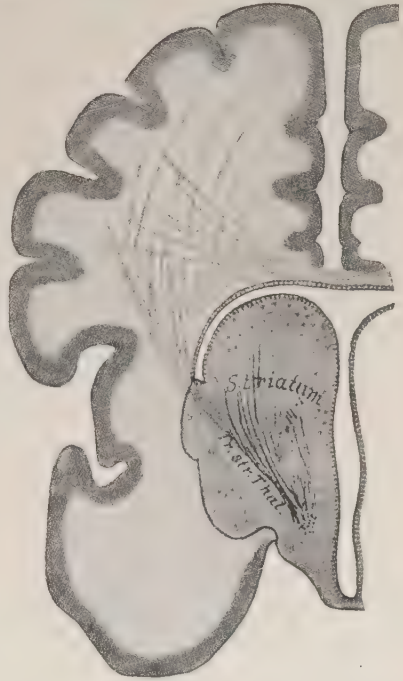


FIG. 118.—Frontal section through fore-brain of a teleostean, *Corvina nigra*, directed obliquely behind and down. Round this the outline of a mammalian cerebrum is drawn, to show the relations between the basal ganglia and the pallium. (Edinger.) (From: Luciani, "Human Physiology.")

these changes throw light on its functional significance, it is necessary to consider them.

The striate body is a primordial structure of the vertebrate brain which, in the lower forms, such as the fish, represents, in the form of a *basal forebrain ganglion*, the highest centre for the correlation of all motor or effector impulses. It receives from the thalamus, and also to some extent, from the mid-brain, their sensory or receptor stimuli, in response to which it originates the correct effector responses. From this basal forebrain ganglion there proceeds a voluminous bundle of effector axons, which form the *basal tract*, or *basal forebrain bundle*. This primitive effector tract appears to be, in fish, amphibians, reptiles, and birds, the homologue of the neopallial corticospinal motor or effector pathway of man. In those vertebrates, such as fish, where there is no neopallial cerebral cortex at all, it necessarily follows that this basal motor tract is the only one which the animal possesses, and it connects the higher co-ordinating parts of the central nervous system with the lower parts. It is, therefore, the oldest motor pathway and is hence termed the *paleokinetic motor pathway*.

By means of this primitive thalamo-striate brain, the receptor thalamus and the effector striate body, there are assured those primitive automatic associated movements, the essential features of which are their constancy, their rhythm, their inter-segmental association, and the automatic nature in which they accomplish a definite purpose. All these features are observable in the constant swimming movements of the fish. With the transference of animal forms from water to land, this constancy of movement, essential to the fish, becomes disadvantageous to the animal on land, and consequently requires some structural alterations in the nervous system.

It is consequently found that with the advent of *amphibious* life, newer parts are added to the basal forebrain ganglion or the paleostriatum, which tend to extend the correlation of motor impulses. This addition is the primitive neostriatum, which first definitely appears in the reptiles, and gradually increasing in size and prominence in birds and mammals,

becomes divided, in the latter, consequent on the addition of the neopallial cortex and the formation of a new motor pathway, into two parts, a caudate nucleus and a lentiform nucleus.

Coincident with the changes which transform the basal fore-brain ganglion into a striate body, there is, as stated, being added a cortical neopallium, to which various nerve functions are transferred, and in which arises a new motor pathway,

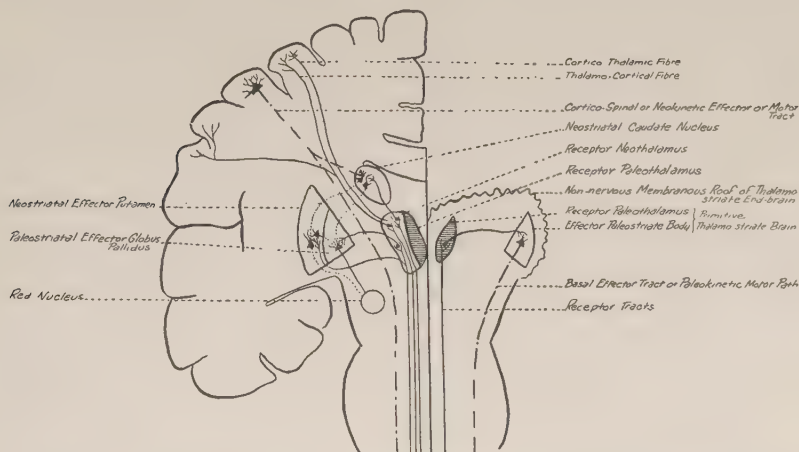


FIG. 119.—A diagram to illustrate the changes in the thalamo-striate brain consequent on the addition of a pallial cerebral cortex human brain on left. Primitive vertebrate on right. See pages 300, 306, 314, 435, 438 and Fig. 87.

the corticospinal or pyramidal pathway, which is hence a *neokinetic motor pathway*. Motor functions, or at least the majority of such functions, thus become transferred from the primitive striate body to the motor neopallial cortex, and the main motor pathway from the primitive basal tract to the corticospinal tract. It is this last pathway which divides the primitive striate body into two parts. In the human brain, therefore, the globus pallidus represents the paleostriatum, and the putamen of the lentiform nucleus and the caudate nucleus, the neostriatum.

These evolutionary changes are also in accordance with the *histological construction* of the parts concerned, inasmuch as the paleostriatum (globus pallidus) consists almost exclu-

sively of effector types of cells, whilst the neostriatum (putamen and caudate nucleus) contain chiefly smaller cells of an internuncial character.

It consequently follows that the primitive neuronic pathways involve the thalamus and the striate body, the former acting as the sensory or receptor head ganglion, and the latter as the motor or effector. All incoming receptor impulses reach the thalamus, which is connected with the effector striate body, whence proceeds an old or paleokinetic motor pathway to the effector organs of the body. With the advent, in the mammal, of a neopallial cerebral cortex, the primitive receptor pathways to the thalamus are retained, and extended thence to the cortex by thalamo-cortical connections. From the cortex a new or neokinetic motor pathway is evolved, which forms the corticospinal or pyramidal tracts, and largely supersedes the striate body effector pathway. It is thus clear that the *thalamus* is retained in the mammal and man as a first receiving ganglion for most incoming receptor impulses, which are then transferred to the cerebral cortex, in which they are extended and stored whilst the functions of the effector *striate body* are largely superseded by this new motor neopallial cortex.

Connections of the Human Striate Body. In the present state of neurological knowledge it is not possible to state, with precision, the exact connections and functions of a portion of the neuraxis which has undergone so much evolutionary change as has the region now in question. In the absence of precise information as to the connections of the human striate body it is advisable to keep the evolutionary changes in view.

The *globus pallidus* appears to be the human equivalent of the primitive effector head ganglion of the fish, in which the motor functions to be fulfilled are different from those of a land animal, inasmuch as they have to be rapid and automatic. In the fish the effector primitive striate body is the chief cephalic motor ganglion, and it is directly connected to the thalamus or receptor brain by thalamo-striate fibres, and gives off, in its turn, a basal motor tract to lower parts of the

neuraxis and the motor effector organs in general. These connections appear to be maintained in a modified form in the human being.

In man the thalamus appears to give off neurons which pass to the globus pallidus, thus retaining the primitive thalamostriate connections. The effector globus pallidus is, in its turn, connected with the red nucleus, the substantia nigra, and the hypothalamic nucleus, and as at least one of the nuclei—the red nucleus—is connected with the final common effector pathway (lower motor neuron), it is clear that the globus pallidus is one of the agencies controlling motor movement in man, and it is probable that the nature of the control exercised is similar to that in the fish, though naturally not nearly so pronounced, because muscular control is, in man, largely exercised by a new element, the neopallial cortex. *Disease of the globus pallidus* might, therefore, result in a suppression of automatic associated movements, hypertonus of the body musculature, the production of more or less pronounced attitudes, and tremor occurring in the resting stage of the muscles, due to the lack of proper myotonic stability. These symptoms constitute the principal features of *paralysis agitans*. (Tilney and Riley.) It is too readily assumed, clinically, that because certain symptoms follow a macroscopic lesion of some part of the nervous system, that the functions arrested or modified reside in the diseased structure. What is forgotten is that disease in one part modifies many other parts, and disease of the globus pallidus is a case in point. Disease of this structure implies that one of the many factors concerned in the control of muscular movement is now impaired or removed, and consequently the remaining portions are, as it were, unrestrained and symptoms are produced which are not necessarily the sole function of the part diseased.

The *putamen* and *caudate nucleus* are more recent additions to the striatal system and are probably neopallial derivatives, though they do not appear to have any direct connections with the neopallial cerebral cortex. The caudate nucleus appears to receive impulses from the anterior and medial

nuclei of the thalamus by means of thalamo-caudate fibres, and Cajal states that collaterals from the corticospinal tracts are also given off to the caudate nucleus. By means of these connections the caudate nucleus would be brought under the influence of receptor impulses coming through the thalamus, and of cortical impulses from the Rolandic motor area. The caudate nucleus, in its turn, gives off axons which pass direct to the putamen, whence the impulses are transferred on to the globus pallidus by means of neurons passing from the putamen to the globus pallidus. But caudate nucleus influence is not restricted to the globus pallidus, because the putamen, which has received impulses from the caudate nucleus, is also connected by axons known as the *ansa lenticularis* with the thalamus, red nucleus, hypothalamic nucleus, and substantia nigra. It is thus clear that the caudate nucleus and the putamen exercise some control over the final common effector pathway (lower motor neuron) by way of the striato-rubral and rubrospinal tracts. It thus appears to be probable that the neostriatal system (caudate nucleus and putamen) functions as an inhibitor of automatic movements, and such an inhibition would be rendered necessary with the transference of animal forms from an aquatic life, with its incessant muscular activity, to a terrestrial one, with more muscular repose.

Disease in the putamen, which apparently contains elements of both the paleostriate and neostriate systems, might, therefore, produce symptoms closely simulating those of paralysis agitans; but distinguished therefrom by a greater degree of muscular hypertonus.

Disease of the caudate nucleus removes, to a certain extent, the control over the globus pallidus, and there is, as a consequence, a liberation or production of abnormal automatic associated movements, that is, choreic movement.

The Internal Capsule. The internal capsule is a broad band, composed of white medullated fibres, which lies between the lentiform nucleus on its lateral side, and the caudate nucleus, terminal stria, and thalamus, on its medial side, and

through which pass the corticospinal, cortico-bulbar and cerebro-ponto-cerebellar fibres.

In *horizontal section* the shape of the internal capsule is characteristic, as it is bent upon itself opposite the terminal stria, the bend constituting the *genu*. About one-third of the capsule lies on the frontal side of the genu, and constitutes the *frontal part* of the internal capsule, whilst the

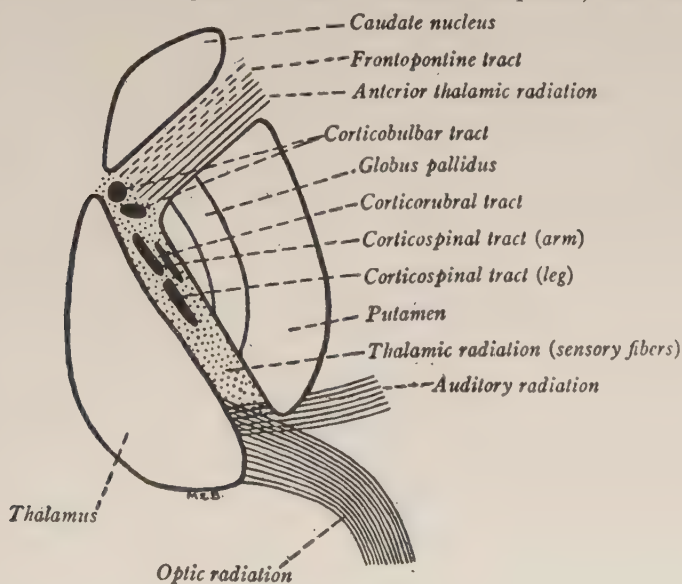


FIG. 120.—Diagram of the internal capsule. (From: Ranson, "The Anatomy of the Nervous System.")

remaining two-thirds constitute the *occipital part*. The former lies between the head of the caudate nucleus and the lentiform nucleus; the latter between the thalamus and the lentiform nucleus.

The *frontal part of the internal capsule* is much broken up by grey matter passing between the constituent elements of the striate body. It consists of fibres passing from the lateral nucleus of the thalamus to the frontal cortex, which form the *frontal stalk of the thalamus*, and of the *fronto-pontine tract* passing from the frontal cortex to the nuclei pontis, and thence, as ponto-cerebellar fibres, to the cerebellum.

The *occipital part of the internal capsule* lies between the thalamus and the lentiform nucleus, and bends round the latter on to its ventral surface. It is thus naturally divided into three parts, lenticulo-thalamic, retro-lenticular, and sub-lenticular.

Through the *lenticulo-thalamic part* are transmitted fibres passing from the thalamus to the cortex and forming part of the *thalamic radiation*. Intermingled with these are the great effector pathways from the cerebral cortex. Of these the *corticobulbar tract*, which passes from the Rolandic motor area to the nuclei of the cerebral nerves, occupies the genu, whilst the *corticospinal tract* occupies the adjacent part of the occipital limb, and its constituent elements are here arranged in definite order, those passing to the arm being nearer the genu than those proceeding to the lower limb. Closely associated with the corticospinal tracts are certain axons passing from the frontal cortex to the red nucleus, and known as the *corticorubral tract*. On the immediate occipital side of the corticospinal tracts the remainder of the occipital limb of the internal capsule is occupied by fibres passing from the lateral nucleus of the thalamus to the posterior central gyrus. These fibres form part of the thalamic radiation and convey general receptor impulses to the cortex.

The *retro-lenticular part* is occupied by parts of the optic and acoustic radiations.

The *sub-lenticular part* contains the temporo-pontine tract from the temporal cortex to the nuclei pontis and thence, as ponto-cerebellar fibres, to the cerebellum.

Lesions of the Internal Capsule. The internal capsule is a common site for cerebral hæmorrhage, or for embolus or thrombosis of its arteries of supply. This is due to the fact that the middle cerebral artery gives off, at the base of the brain, lenticulo-optic and lenticulo-striate branches to the striate body, which, owing to the pooriness of their anastomoses, are known as "end arteries." The lenticulo-striate artery runs along the lentiform nucleus and supplies the region of the internal capsule. On account of its small size

and the lack of support afforded it, it is peculiarly liable, in the aged, consequent on increased blood pressure and degenerative changes in the arterial walls, to rupture, and is hence known as *the artery of cerebral hæmorrhage*. Whilst arterial degeneration is liable to occur in any patient of advanced age (senile degeneration), its onset is hastened by previous alcoholic excess, chronic lead poisoning, and syphilis.

A hæmorrhage in the vicinity of the internal capsule or other part of the brain naturally produces symptoms in two distinct ways, one, by the rise of intra-cranial pressure which it produces, and, two, by destroying the functions of the nerve fibres in the particular locality in which it occurs. As a hæmorrhage within the internal capsule cuts off a very large number of cortico-spinal fibres, there is usually paralysis of the opposite side of the body (hemiplegia) in addition to the other well-known signs of a cerebral apoplexy, such as complete unconsciousness, stertorous breathing, full, slow, bounding pulse, and a turgid countenance.

The External Capsule. The external capsule is a thin lamina of white matter which lies between the lentiform nucleus on its medial side, and the claustrum on its lateral side. It is united to the internal capsule on both sides of the lentiform nucleus, which is thus encapsulated in white matter.

The Terminal Stria. The terminal stria is a narrow band of white fibres which arises mainly in the amygdaloid nucleus. It passes thence in the roof of the temporal horn of the lateral ventricle, and, gaining the floor of the central part of the lateral ventricle, lies between the caudate nucleus and the thalamus. At the inter-ventricular foramen the terminal stria turns towards the anterior commissure, to terminate in the anterior perforated substance.

Chief Sites of Neuronic Arcs in Man. Development, evolution, histology, and pathology, all point to the fact that the central nervous system, in its long and gradual evolution from the simple reflex activities of the lower and unconscious animal forms to the highly evolved and involved mental and con-

scious manifestations of man, has passed through a series of phases of ever-increasing complexity of neuronic arcs.

The main types of these arcs, as set forth in evolutionary order by Ramon y Cajal, are as follows:

1. The *epoch of irritability*, in which a receptor cell receives the stimulus and transmits directly to an effector cell. This constitutes the nervous mechanism of sponges and the receptor cell reacts to a chemical or physical stimulus. The myenteric, and possibly other reflexes in the walls of the alimentary canal, appear, in man, to be of this type.

2. The *epoch of the reflex arc*, in which the receptor cell of the sponges becomes elongated to form a special conducting nerve element. It transmits its impulse to a similarly elongated conducting effector cell, and thus there is formed a simple neuronic arc composed of two elements only, with no interposed junctional or internuncial neurons whatsoever. Such a type of nervous system is found in the coelenterates and gives a quick, but unconscious, response of several parts of the body to the incoming receptor impulses. The central spinal cord connections of the autonomic nervous system of man appear to belong to this type.

3. The *epoch of the inter-segmental reflex neuron*. The units of the neuronic arc are here increased by the presence of one or more internuncial neurons interposed between the receptor and effector limbs of the neuronic arc. As each neuronic element of the neuronic arc is anatomically separated off from the others by the interval known physiologically as the synapse, the synapses give the added possibility of branching discharge of nerve impulse to the neuronic arcs of other segments. This form of nervous system is characteristically seen in the earthworm. In man, it forms the bulk of the segmented part of the neuraxis—spinal cord, medulla, and pons—and the internuncial neurons are, anatomically, of the association and commissural types. The mode of reaction is reflex and largely unconscious, but the presence of the numerous synapses gives the added possibility of the nerve impulses flowing over from the segmented neuraxis to the supra-seg-

mental cerebral cortex, and so arousing consciousness, or a vague form of consciousness, often, though quite erroneously referred to as the *subconscious mind*, an unfortunate expression which is merely a contradiction in terms. In man there is to be noted the further possibility afforded by the presence of these innumerable synapses that, in disease, nerve impulses from other arcs may enter at the synapses and so produce abnormal responses.

4. The *epoch of the supra-segmental reflex neuron*. In higher animals which have passed beyond the stages of a purely segmental neuraxis into that of supra-segmental additions, the latter are provided with new nerve elements introduced between the receptor and effector limbs of the supra-segmental neuronics arcs. These new additions are innumerable short or granular neurons which are strictly limited to the grey matter in which they are found. They are not, therefore, conducting in type, but constitute storehouses for incoming receptor impulses. With the introduction of such nerve elements there is thus introduced the function of *inhibition* and the effector response to the incoming receptor impulse need no longer be immediate and reflex, but may be delayed and "psychic." The cerebellum of man and of all cerebellar animals is a typical and instructive example of this type of nervous system.

5. The *epoch of the psycho-associational neuron*. The final step in the centralisation of the nervous mechanism, enabling it to attain the consummation of its functional capacity, is reached with the epoch of the psycho-associational neuron, and attains its highest development in man. Here there are no new nerve elements introduced. The neuronics machinery employed is a combination of the inter-segmental reflex neurons (association and commissural) and the supra-segmental reflex neurons (granular). It is typically seen in the cerebral hemispheres and in all portions thereof, that is, the infra-granular cortex with its polymorphic cells; the supra-granular cortex with its pyramidal cells; and the association areas compounded of both. Disease or lack of devel-

opment of these cerebral neurons necessarily alters mentality, and may do so so profoundly as to give abnormal reactions to the environment, some of which are termed insanity, whilst others are simply ignored and it is thought the patient will

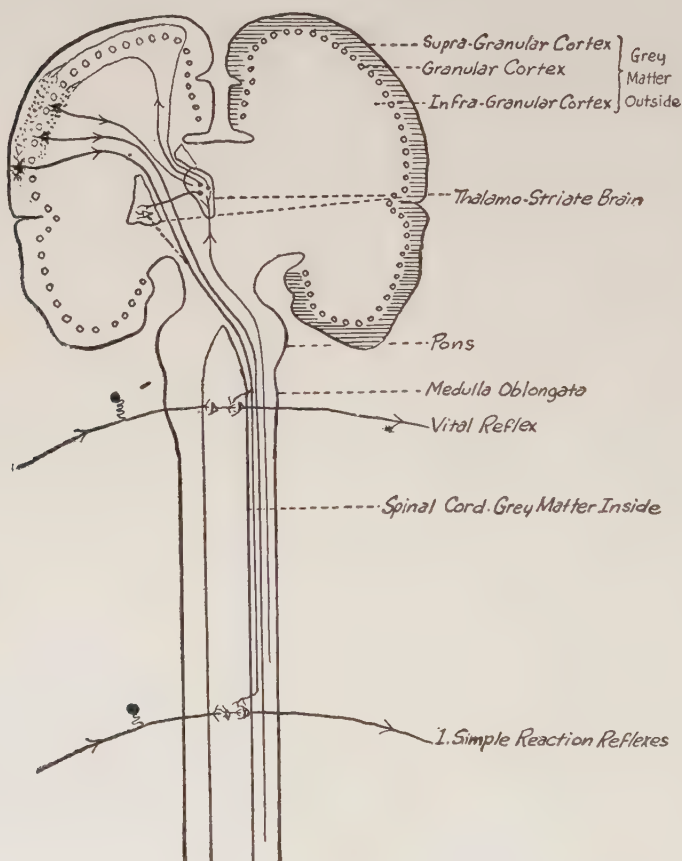


FIG. 121.—Diagrammatic summary of nervous system.
See page 447.

grow out of it, in defiance of the fact that no new neurons arise after birth, and in ignorance of that knowledge of the structure and functions of the nervous system which is essential to the study of mind and its disorders.

General Conclusions. There are, therefore, in man certain great sites of reflex unconscious, automatic, and conscious activities, which are as follows:

1. The spinal cord, through which are mediated many of the reflex and usually unconscious entero-ceptive activities of the autonomic nervous system.

2. The simple reflexes of reaction to physical stimuli with their centres in the spinal cord, and typically exemplified in the segments of the earthworm and the knee-jerk of man.

3. The reflexes of the vital functions of life, such as breathing and the control of the heart, with their centres in the brain stem.

4. The reflexes of the primitive emotions of the lower animals, through the thalamo-striate brain, that is, the endbrain of such animals, and therefore uncontrolled. In man this brain has largely passed under the dominion of the neopallial cerebral hemispheres.

5. The animal, reproductive, and instinctive reflexes of mammals and man, through the infra-granular cortex of the neopallium.

6. The mental reactions of man through the supra-granular cortex and the association areas of the brain.

PART II
THE NERVOUS SYSTEM IN HEALTH
AND DISEASE

CHAPTER XXXIV

IMPORTANCE AND SIGNIFICANCE OF THE NERVOUS SYSTEM

Introduction. In the first part of this work there has been set forth a structural and functional account of the nervous system of man. Without this elementary knowledge it is impossible to diagnose or treat the numerous diseases to which the conducting portions of the nervous system are liable, and it is even more impossible to understand the aberrations of the human mind, from either mal-development, disease, or destruction, without a still more intimate knowledge of normal cortical structure and function. The burden of diagnosis of nervous and mental disorder is placed upon the medical profession, but it is unhappily only too common to find some members of that profession discussing and treating the disorders of the mind, without that thoroughly sound knowledge of the anatomy, physiology, and pathology of the brain and spinal cord which is so essential; whilst any study of the everyday phenomena of the nervous system in ordinary health is simply ignored. In view of the large amount of attention devoted, especially by those who are often quite ignorant of brain structure and function, to what is termed psychology, as well as to psycho-analysis, self-introspection, and the borderlands of spiritualism, it cannot be too strongly urged, and remembered, that the formula is—*no neuron, no mind*. To bridge this gap between the everyday functioning of the nervous system and its diseases is the object of this second part, and although this necessarily demands a certain amount of repetition the reader will be assumed to have mastered the first part, and to be familiar with the elementary facts regarding the nervous system therein set forth.

Origin of the Nervous System. Every human being is developed from a single cell or ovum, which, after fertilisation, undergoes a long and complex series of changes, by means of which there is produced a new individual which, within the limits of ordinary variation, is like the parents that gave it birth. From the study of these changes are derived our conceptions of the nature of sex, heredity, variation, differentiation, and many of our most important notions concerning evolution, both of the individual and the race. It thus follows that if one or both parents have an underdeveloped or weak nervous system the offspring is likely to inherit the same.

Subsequent to birth a further series of changes occurs, to which the term *development* is applied. These changes include the processes of growth, the development of muscle, the adaptation of the brain to its intellectual functions, and many others. Any or all of these post-natal changes may not proceed to full development, in which case the child will be more or less seriously hindered from performing the normal functions of adult life. If it be the nerve cells which do not attain full development, some form of amentia or feeble-mindedness must result, though only too frequently the condition is not recognised and the parents are told "the child will grow out of it."

Subsequent to fertilisation the single-celled ovum divides into two segments or *blastomeres*. These divide to form a group of four segments, which again cleave into eight, and this process of binary cell division is continued until the original single-celled ovum becomes converted into a many celled mass, termed a *morula*. From this multi-celled morula there will eventually be developed the countless millions of cells which go to form the human body. With further development these cells will become specially modified to form the bone cells, liver cells, muscle cells, brain cells, and so on.

Neurology Versus Psychology. It is a very widespread, but quite erroneous belief, that *neurology* concerns only the nerves, whilst *psychology* is concerned with the mind, and

that the two have nothing in common. Only too frequently psychologists are found who are quite ignorant of the structure, functions, or diseases of the human brain, and yet it is commonly believed that only such can explain the phenomena of mind. It is unhappily only too probable that *psychology* "suggests an exploration of the recondite mysteries of human existence, of human experiences and activities. No wonder that it serves as a catchpenny for the unwary and unthinking, for those who are only too eager to adopt new views and doctrines in the belief that such an attitude places them in the forefront of intellectual progress." (Dercum.) *Neurology*, on the other hand, constantly seeks to correlate structure with function, to observe how disease or mal-development alters the individual's reactions to the environment, and to check its observations, at all points, by comparative anatomy, experiment, embryology, and laborious research. *Neurology* is, therefore, the only true psychology and only neurology can explain the phenomena of mind, because it alone studies the neuron, which is the physical instrument of mind.

If Psychology be defined, as by MacDougall, as the "positive science of the behaviour of living things," then it is in strict accordance with *Neurology*, because the latter science teaches that every living thing reacts to stimuli derived from two great sources, those from within the body itself, and those which come to the brain from without. The *mode of reaction to these stimuli constitutes behaviour*, and these reactions, and consequently behaviour itself, depend, in the first place, entirely on the number, nature, and relative state of development of the neurons. An insufficient number of neurons, an imperfectly connected series of neurons, or an imperfect insulation (myelination) of their axons give marked differences in the display of intelligent action, that is, in the behaviour of the individual. Depending on the degree of arrested neuron development, there results some form of idiocy, physical imbecility, moral imbecility, morosity, or feeble-mindedness, in all of which cases the neurological reac-

tion of the individual to his environment, that is, his behaviour, is strikingly different from that of the normal individual. That this difference in "behaviour," that is, the reaction to the environment, is due to lack of neurons is abundantly proved by a study of the brain weights of microcephalic idiots, and, more recently, of the relative thicknesses of the cortical layers of the brain. All neurologists are agreed that with brains of a smaller size than 930 grammes there can be no human intelligence.

Dependence of Intelligence on Two Factors. Intelligence depends on two factors, the number and nature of the neurons, and the number and nature of the incoming receptor impulses. The proof of the *former* is furnished by the human microcephalic idiot, where the neuron development is arrested at about the level of the eighth month foetus. The *latter* is proved by that form of idiocy termed idiocy from deprivation of the senses. The great importance of the receptor neurons is further shown by the facts that they are always more numerous than the outgoing effector neurons, are the first to be developed, and are also the first to myelinate. It follows, therefore, that before there can be any display of "mind" or intelligent action, there must first be an inpouring of receptor impulses. The brain must receive before it can give out the effector phenomena associated with mind. The individual thus reacts to his surroundings (neurology), or behaves (psychology), and the nerve mechanism by which this is accomplished is always the same, namely, through combinations of neuron arcs.

The form of the nervous system is always correlated with the behaviour of the animal possessing it. In other words, its psychology or behaviour is entirely dependent on its neurology. "Most of the types of nervous systems found in the animal kingdom are represented in two distinct and divergent lines of evolution, one adapted especially well for the reflex and instinctive mode of life and found in the worms, insects, and their allies, and the other found in the vertebrates and culminating in the human brain, with its remarkable

capacity for individually acquired and conscious functions." (Herrick.)

The Co-ordination of the Incoming Receptor Impulses. It has just been stated that receptor impulses are continually being poured into the nervous system, and that without such impulses there can be no mind. These numerous incoming impulses must be combined somewhere within the nervous system in order to give a suitable effector response. This "somewhere" is, in the earthworm, for example, the cephalic nerve ganglion or "brain," which is, therefore, a *correlation centre*. If the receptor impulses be few, as in the earthworm, the cephalic ganglion will be simple; if many, as in man, the brain will be correspondingly complex. Receptor nerve impulses reach this correlation centre, and the effector reactions which follow will be the resultants of the interactions of all these incoming receptor impulses. It follows, therefore, that the cephalic ganglion or "brain" will be composed structurally of internuncial neurons, rather than of conducting neurons, and that the properties of such neurons will be those of correlation, integration, association, and storage of nerve impulses from the body of the individual, and to such portions of the external physical world as the life form is attuned.

Different Types of Correlating Brains. At the head end of successive evolutionary types of animals Nature continually adds on a new *co-ordinating brain*. There is first the midbrain, then the thalamo-striate brain, next the infra-granular cerebral cortex of mammals, and lastly, there has been added, in man, a supra-granular cortex with association areas. In every instance the nerve mechanism is the neuron arc, which becomes more and more complex with each evolutionary addition. If we had a perfect knowledge of all the connections of these excessively complex neuron arcs in the more recent evolutionary additions to the central nervous system, and knew the nerve paths affected by any given stimulus, "we should be able to prophesy exactly the result of such stimulus," that is, what the exact behaviour of the

individual would be. "In the cases of the simpler reactions," both in animals and man, "this is already possible" (Starling), but in the higher parts of the nervous system the enormous complexity of the neuronics arcs and their connections excludes any possibility of our forming more than a general idea as to how the individual will react, mentally, to receptor or incoming impressions. The emotional and psychic reflexes—which are largely delayed responses to the stimuli, instead of immediate, and involve the higher parts of the most recently added parts of the nervous system, that is, those with the greatest complexity of neuronics arcs—are usually, but erroneously, regarded as being the special province of Psychology. That is, if a science which specially studies, by every available means, the physical mechanism of mind, is unable to follow the multitudinous pathways of the cerebral arcs, it is thought that a pseudo-science with no such knowledge, can do so. "A study of mind from the standpoint of physiology leads to the realisation that the 'physiology of mind' embraces what is ordinarily meant by 'psychology.' In any event psychology can only be regarded as a department of brain physiology." (Dercum.) It is thus clear that the study of mind and its disorders absolutely necessitates a most thorough knowledge of the anatomy, histology, physiology, and pathology of the brain, and this knowledge the lay psychologist does not usually possess. The real difficulty in correlating psychology (the physiology of mind) with neurology (structure and function of the brain) lies in the fact that as we pass from the simple reflex neuronics arcs to the highly complex, which involve mind and intelligence, we become less and less familiar with the extraordinary complexity of the paths followed by the neuronics arcs involved. There is, however, no doubt at all that the same type of neuronics machinery which serves for the simpler reflexes is also utilised by nature, though in an immensely more involved form, for the display of the emotions and of mind. Hence the formula, which cannot be too strongly emphasised, "*no neuron, no mind.*" Lastly, even the cerebral complexities of the neuronics

arcs are beginning to be understood, as this work has endeavoured to show.

Development of the Individual. At birth, the newborn infant is little more than a splanchnic, or visceral, series of hunger reflexes. With growth and medullation of neurons there follow the acquisition of certain physical properties, such as sight, hearing, smell, taste, touch, and so on, all of which increase the range of consciousness. Simultaneously with the acquisition of these properties, many visceral or splanchnic receptor impressions are added which inform the individual of the state of his own body. With the acquisition of speech and the rudiments of education still more neurons assume their function, and the range of consciousness is still further increased, and so on, till the full complement of sensory or receptor impressions is acquired—always provided there be no arrest of neuronie development. As all these involve neuronie reflex paths and a general synchronisation in the cerebral cortex, and as these receptor impressions and impulses differ materially in different individuals, it follows that no two individuals have exactly the same mind or the same outlook on life.

That the recently acquired neopallial cerebral cortex controls individual behaviour, that is, the reaction to the environment, is undoubted, and that these reactions depend entirely on the number and connections of the neurons is equally certain. The neopallium has, therefore, assumed control over the whole central nervous system of man. If, however, that cortical neopallium be not fully informed of the conditions of the body itself and of the external world around it, it cannot function in a normal manner, and hence the very great importance of the incoming receptor impulses, to which attention may now first be directed.

CHAPTER XXXV

THE NUMBER, NATURE, AND IMPORTANCE OF THE IMPULSES CONVEYED CENTRALLY OVER RECEPTOR NEURONS

Three Great Kinds of Receptor Impulses. In an earlier part of this work something has been said of Sherrington's researches which have familiarised most medical men with the incoming to the brain of entero-ceptive, proprio-ceptive, and extero-ceptive impulses from different sources. Whether the real significance, and profound influence on brain structure and mental outlook of these impulses are equally well understood is more open to doubt.

The *entero-ceptive group* comprises a general visceral group, such as hunger, thirst, nausea, respiratory sensations, circulatory sensations, sensations of distension of cavities, visceral pain, and obscure abdominal sensations, as well as a special visceral group, such as taste.

The *proprio-ceptive group* comprises muscular sensibility, tendon and joint sensibility, and static and equilibratory sensation.

The *extero-ceptive group* comprises impulses proceeding to the brain from the external physical world, such as those of vision, hearing, deep pressure, tactile sensibility, all forms of cutaneous sensibility (touch, temperature, pain), stereognostic perception, general chemical sensibility and smell—this last a sense which has almost disappeared from the human senses.

A complete list of these various receptor impulses, so far as known, has been furnished in the first part of this work. It, therefore, now suffices to say that in every instance, there is provided a receptor organ, which apparently varies from a naked axon to such a complicated structure as the organ

of Corti. This receptor organ acts, as it were, as the intermediary between the particular stimulus and the neuron to be stimulated. A chemical stimulus within the alimentary tract may stimulate a receptor organ and so cause the appropriate axon to convey a nerve impulse to some part of the neuraxis. Light waves falling on the retina—the receptor organ for sight—similarly arouse the axons of the optic nerve to transmit impulses to the cortex. Whilst many of these specialised receptor organs are known and described, it is probable that there are others which have not yet been definitely located.

Some Examples of the Results Produced by Incoming Receptor Impulses. Entero-ceptive and proprio-ceptive impulses are largely concerned with the internal bodily world, and a very large proportion of these impulses never enter into consciousness and yet occasion actions which are perfectly adapted to the end in view. That is, although they do not arouse consciousness they yet produce purposeful reflex actions. The whole life of the common earthworm is an example of purposeful reflex activity without consciousness.

In the human being, where many visceral entero-ceptive impulses are being continually transmitted centrally, there is an appropriate, but unconscious, reflex effector action in response to the receptor stimuli, as, for example, the secretion of the lacrimal fluid stimulating the effector closure of the eyelids. In other cases, as for example, the testicular secretion, the entero-ceptive impulses only rise to consciousness, in the form of desire, when a sufficiency of such impulses have been transmitted centrally so as to overflow, as it were, from the reflex centres in the spinal cord, to the brain. This, however, is only one of the many ways in which sexual desire is aroused.

A visit to the Zoo will illustrate the purposeful reflex activities called up by entero-ceptive impulses. A little prior to feeding time, carnivorous animals in confinement, show signs of motor excitement, which becomes more pronounced as the keeper approaches. Here deprivation of food has produced

certain changes in the stomach which are transmitted by entero-ceptive neurons to the nervous system, and arouse impressions of hunger. Under natural conditions the animal would be stimulated by these impulses to undertake the correct effector responses of stalking, seizing, and devouring its prey. Under artificial conditions this is impossible, and hence the motor responses assume the form of apparently purposeless movements around the cage. As the sense of smell is much better developed in such animals than in man, they smell the keeper with the food long before the spectators see him, and the motor or effector activities become correspondingly more active.

The human being resembles the animal as regards entero-ceptive impulses and their translation into the corresponding motor responses, both as regards food and sex, but differs from the animal in his voluntary control over, or inhibition of, the effector responses, because he has been furnished with a cortical brain of control, in the pyramidal celled supra-granular cortex.

The Two Dominating Factors of Life. The two great dominating factors of life are hunger and sex, and of these, the former is the more important, on account of the increased frequency with which it must be satisfied, and the fact, that if it be not so satisfied, the individual dies. Hunger, therefore, is the greatest of all neurological driving forces and man is no exception to this universal law of nature.

Man is a sexually omniprevalent animal, hence there are certain schools of continental psychology which attribute many normal, and almost all abnormal, mental phenomena to sex rather than hunger. The law of self-preservation precedes that of the species. Give a starving being—animal or human—the opportunity of satisfying either its somatic or its sexual hunger and it is certain that it is the former which will be first assuaged, hence hunger is the greater of the two driving forces, and both hunger and sex compel the performance of certain effector responses as a result of the incoming receptor impulses.

Neurological Analogies Between Hunger and Sex. Between these two great dominating factors of life, hunger and sex, there is a close neurological analogy. In both there are hollow viscera capable of varying degrees of distension, though in the one case it is the full viscus which stimulates the neurons, and in the other the empty viscus. These varying degrees of distension constantly arouse entero-ceptive impulses which pass through the autonomic nervous system to the central nervous system. In both instances these primary impulses become commingled in the cerebral cortex with the appropriate secondary extero-ceptive ones, and it follows that in both cases the desire for food or sex may be aroused by either the primary or the secondary impulses. From time to time these overpower, in each case, all other nerve impulses, and must be followed by the appropriate motor or effector response.

Hunger and the passion of desire *differ* from each other in two important respects. The one, *hunger*, is a constant feature of life, from birth to death, and cannot be inhibited by the individual, that is to say, death follows a lack of the correct motor response. The other, *sex*, is a desire limited to the prime years of life only, and man is the only animal endowed by Nature with a brain of voluntary control or inhibition over the appropriate motor or effector responses. That he not infrequently fails to do so causes no surprise to the Neurologist familiar with the clinical history of the ament. A total suppression of the appropriate motor responses causes, in the one case, the death of the individual, in the other, death of the species. Hunger is, therefore, from the personal standpoint, the more important of the two great driving forces of life.

The Passion for Reproduction. The passion for reproduction is strongly implanted by Nature in all living animals, and is, indeed, essential to the perpetuation of the species. It is further clear that the nerve phenomena connected with the mechanism of reproduction are admirably adapted to their purpose.

As the male represents the active instrument in sexual

congress, Nature ensures a constant repetition of desire by a perpetual secretion, during the whole of sexual life, of the germinal cells of reproduction. The result is that, after puberty, the testes and seminal vesicles are constantly undergoing distension, and corresponding entero-ceptive impulses are as constantly being transmitted to the cerebral centres. In due course these impulses become sufficiently strong as to master all other cerebral impulses and sexual desire results. "In many instances, an infinitesimal stimulus travelling up a few nerve fibres may excite widespread activity of the whole central nervous system with the discharge of impulses along practically every nerve of the body." (Starling.)

In the males of all lower vertebrates there can be little question that the foregoing represents essentially what takes place, and it may not be improbable that the process is stimulated at certain times of the year by a seasonal quickening in the rate of production of the spermatozoa, aided, perhaps, by extero-ceptive olfactory impulses from the female. Even though this be incorrect, it appears to be certain that there are periodical bodily alterations in the lower animals which induce sexual desire at certain seasonal periods, as, for example, the alterations in the position of the testes at the "rutting" season, and the vascular changes in the common fowl, which after a period of egg-laying, transfer the blood supply from the ovary to the surface, and produce the desire to "sit." As the fowl will sit whether there be eggs under or not, it is obviously entero-ceptive impulses which arouse the desire, and not extero-ceptive ones derived from the sight of the eggs.

In man there is no doubt that the same primitive mechanism is retained. There is the same process of spermatozoon formation, the same provision for storage and discharge, the same entero-ceptive nerve routes, but there is this great difference. The motor response may be controlled or inhibited by the greatly extended supra-granular pyramidal brain. If the cells of this layer of the cortex be deficient in numbers, or remain imperfectly developed, as is the case in many aments, these powers of inhibition will be correspondingly diminished,

and the sexual appetite will be gratified more frequently and with less foresight.

Whilst it is perfectly true that sexual desire may be aroused in children before the age of puberty, it is very doubtful if this is brought about by entero-ceptive impulses from the sexual organs. It seems more probable that it results from extero-ceptive impulses from the skin, the results of irritation. In slightly older children it may also be aroused through extero-ceptive impulses of sight and hearing, in other words, that sexual desire may be aroused in children below the age of puberty by the improper use of "education" is undoubted, and may be responsible for much mischief, as the habit may be established before the cortical control.

In the adult there is, of course, a commingling within the cerebral cortex of all the impulses concerned with sex—entero-ceptive, proprio-ceptive(?), and extero-ceptive—so that desire may be aroused naturally from distended sexual organs, or secondarily from sight, hearing, touch, or thought. Both primary and secondary avenues are, of course, devices employed by Nature to ensure the perpetuation of the species.

In the female, there appears to be a similar primary and secondary causation of desire, the primary being due to the passage of the ovum from the ovary and the coincident histological changes in the ovary itself.

Logical Results from the Neurological Study of Desire. From this neurological study of the phenomena of desire certain logical results seem to follow.

That, within general limits, the occasional occurrence of nocturnal emissions, with, or without, erotic dreams, is a normal physiological process, about which much nonsense is not infrequently talked. If the erotic dreams be very pronounced or very frequently repeated it is pretty certain that the waking thoughts have been strongly running on sexual matters.

That, whilst the calls of sex are undoubtedly a driving neurological force, there is no physical foundation for most of the puerile indecencies of certain Continental schools.

That control over sexual thoughts and reactions depends on

the state of development of the inhibiting supra-granular layer of the cortex, and that, where this is deficient, as in many aments, it is more than likely that therapeutic treatment by suggestion or psycho-analysis will be productive of more harm than good, because, by directing the patient's attention to the condition, it may actually stimulate, rather than inhibit, the secondary causes of desire. (See Case 2, page 550.) If the cortical controlling cells are not there, no human agency can put them there.

Whilst it is not true, as taught by certain philosophers of the Freudian school, that aberrant mental phenomena are the result of suppressed sexual desires—for their suppression is, in man, a perfectly normal physiological function, for which adequate neurological machinery is, in the normal man, provided—it is indisputable that some mental aberrations have their basis in the entero-ceptive stimuli from the sex organs. This is particularly the case in those aments, in whom the controlling brain is under-developed and in a neuroblastic condition. It is also the case in perfectly normal individuals where, as a result of the onset of adolescence, a totally new series of powerful entero-ceptive impulses begins to be passed in to the brain with results which neither the individual concerned, nor society at large, always understands. Every medical man must be more or less generally familiar with the mental disturbances not infrequently displayed by patients, who, shortly after adolescence, come complaining of nocturnal emissions. Speaking generally and guardedly the latter are a natural sign of life of continence, and their absence, of unchastity. The patient may, therefore, be reassured and it is the duty of the medical man to do so on physiological grounds, for a mind disturbed is a mind impaired.

Great Importance of Receptor Impulses in Moulding the Cortical Neuronic Pattern of the Brain. In the study of mental phenomena, and of diseases of the nervous system and body generally, an altogether insufficient amount of attention has, so far, been devoted to this important question of incoming entero-ceptive, proprio-ceptive, and extero-ceptive

impulses, and their influence in ceaselessly modifying the pattern of the neuron structure of the brain.

Simply expressed, the human brain is continually being bombarded throughout the whole of life, even from before birth, sleeping or awake, in health or disease, by innumerable nerve impulses from bodily structures, organs of locomotion, and the external physical world. These stream into the human brain, and ceaselessly modify the pattern of its structure by causing more and more short and long association cortical neurons to myelinate, that is, to function. New neuron routes are, therefore, continually being added. Older ones are superseded by new ones, and as a result, memory is continually changing, and former impressions are forgotten, and the individual's mental outlook on life is perpetually altered. It is doubtless an inability to realise the vast importance in the formation of mind, of these incoming entero-ceptive, proprio-ceptive, and extero-ceptive impulses, and the fact that many of them come in equally well during sleep, that has caused some post-war writers to advance the most fantastic hypotheses concerning dreams and sex, and to do so in defiance of all evidence.

Individual Differences in the Intensity of the Receptor Impulses. In the study of mental phenomena it is again not nearly sufficiently realised that animals differ from man, and individual men from each other, in the intensity of their extero-ceptive impulses, and that these differences are largely due to differences in the nature of the receptor organs and the numbers and mode of connections of the neurons concerned. The range of the several senses has already been given. (See page 109.) It was further pointed out that many of the lower animals have very different limits of sensibility from those found in man, and in some cases they have sense organs which are attuned to respond to a quite different series of environmental factors than are man's, as, for example, the lateral line organs of fishes. We can form no idea how the world appears to such organisms except in so far as their sensory equipment is analogous with our own. (Herrick.)

It consequently follows that a human individual with an insufficiency of cortical neurons, as, for example, the microcephalic idiot, or the idiot from deprivation of his senses, must have a totally different outlook on the world, from the normal man, and even more, from the multi-neuronic man of genius. It is, therefore, very difficult, if not actually impossible, for the normal mind to understand the mentality of the abnormal, and the reading of the former into the latter is a fruitful source of error, because, on account of neuronic differences, the motor and mental reactions to the stimuli of the environment will be quite different.

There can be no question that ignorance, or lack of appreciation, of the differences produced by these varying incoming extero-ceptive and other impulses is productive of much erroneous thought and even more foolish speculation. A dog occasionally finds its way home over long distances and this is believed by certain credulous individuals to be due to clairvoyance. Hence the statement that "the evidence in favour of clairvoyance is so strong that there can be no doubt that it is founded on fact." The real evidence is, of course, quite the reverse, inasmuch as the dog which does find its way home again is the exception, not the rule, and the dog is a macrosmatic mammal with a powerful sense of smell, and a corresponding greatly increased number of cortical olfactory neurons. It is, therefore, impossible for man to form any adequate idea as to what the universe looks like to a dog. Ignorance of a simple physical fact thus leads to extravagant claims for clairvoyance.

Results of the Deprivation of the Receptor Impulses. It is equally instructive to study the effects upon the mind of partial deprivation of these incoming receptor impulses, and to note the effects of such absence on the cortical neuronic pathways concerned.

In the case of children deprived of the senses of hearing and vision from birth there results the well-known condition "idiocy from deprivation of the senses." Such children experience fewer sensations than healthy children and are, there-

fore, mentally deficient. The congenitally blind or deaf never suffer from hallucinations of sight or hearing, whilst those in whom blindness or deafness is acquired frequently suffer from such hallucinations when they become the subjects of mental disorder.

The effects of a deprivation of a correct number of incoming receptor impulses on brain structure is again well illustrated by the well-known case of Laura Bridgman. She is stated to have been a normal child, who, as a result of a severe attack of scarlet fever at the age of two years, became deaf and blind, taste and smell being also impaired. She lived to be 60 years of age. The post-mortem examination showed various cerebral abnormalities, subsequently worked out by Donaldson. The thickness of the cerebral cortex was carefully measured in 14 different regions in each hemisphere and compared with the average thickness found by measuring homologous areas in 9 normal brains. In exactly those portions of the cortex corresponding with the deprived senses there was a pronounced thinning of the cortex, that is, there was a diminution in the number and size of the neurons concerned. This was greatest in the visual, auditory, taste, and olfactory cortices. "The evidence," says Goddard, "seems conclusive that the centres of the brain not stimulated did not develop." Persons with undeveloped brains must have a diminished intelligence.

That deprivation or diminution of incoming entero-ceptive, proprio-ceptive, and extero-ceptive impulses does actually alter brain neuronie pattern is, therefore, no mere theory. It has been observed. Bolton's "The Brain in Health and Disease" contains many examples. For instance, when speaking of the visual cortex, he says, "in the area of special lamination, in cases of old-standing optic atrophy the line of Gennari is decreased nearly 50% in thickness, and the outer granule layer more than 10%. In the visuo-psychic region surrounding the area of special lamination, old-standing optic atrophy causes no modification of the lamination. In *anophthalmos* the conjoined outer granule layer and line of

Gennari (for the granules in the former layer are not sufficiently obvious to admit of easy micrometric measurement alone), are narrowed down to two-thirds of the normal thickness, the other layers of the cortex being approximately unchanged. This amount of narrowing is the same as that found in cases of old-standing optic atrophy." In anophthalmos no light falls upon the optic nerve neurons, which are thus not stimulated to development by extero-ceptive stimuli with the cortical results observed by Bolton. The profound influence of receptor stimuli on the cortical neuron pattern, and therefore on mentality, is thus proved.

Studies on the Living Subject. The author's original investigations on many thousands of living children are confirmatory of the striking effects produced by a deprivation of a sufficient number of normal incoming receptor impulses. That a congenital deprivation of certain extero-ceptive impulses, such as sight and hearing, which play such an important part in education, leads to an appreciable diminution in head size and cubic capacity of brain is shown by the following:

13 year old normal boys	1352cc.
13 year old deaf and dumb boys	1307cc.
13 year old mentally deficient boys	1292cc.

Expressed in terms of years of cerebral growth, the deaf and dumb boys are 3 years retarded as a result of their deprivation of acoustic receptor impulses, and the mentally deficient boys, 4 years.

Importance of Myelination to Mentality. Attention has already been directed to the importance of myelination in medullated axons and of the part this process takes in function and increase of brain weight. Flechsig has shown that myelination does not occur simultaneously in all parts of the nervous system, but is later in proportion as the nerve fibre (axon of the neuron) is more recent in the phylogenetic history of the animal. Not only are the entering receptor neurons of the spinal cord more numerous than the outgoing effector neurons, but they develop or myelinate earlier, in

order that they may function earlier. Generally speaking the same holds good for the neopallial cerebral cortex, and the last of the cortical neurons to myelinate are those associating, or linking together, the association areas of the cortex, and these are precisely the areas which are universally regarded as being the seats of the higher mental processes. But if these same areas are not stimulated by suitable incoming receptor impulses their association neurons will not myelinate and consequently the areas remain throughout life veritable "silent" areas, to the detriment of the mentality of the individual.

It consequently follows, and it is a strikingly significant fact, that the general order of acquisition of the nerve properties essential to life are:

1. Transmission of entero-ceptive impulses from viscera by means of both non-medullated and medullated fibres through the autonomic nervous system.

2. Transmission of proprio-ceptive impulses, concerned in locomotion.

3. Transmission of extero-ceptive impulses such as touch, pressure, sight, hearing, etc.

4. The last series of neurons to myelinate, that is, to function, are those of the cortex which correlate and control the incoming entero-ceptive, proprio-ceptive, and extero-ceptive impulses, and extend them through the association areas, thus making possible education, speech, thought, and reason. If the neurons of this series fail to myelinate, there must follow an impairment of intelligent action, and a reaction to the environment on a lower plane.

The period of time occupied by the myelination of these four great developmental series is a long one, but differs very considerably in different individuals. It commences before birth, and goes on, in the educated classes until well on into middle life, because education, that is, the constant submission of the cortical association areas to appropriate incoming receptor impulses, is a powerful stimulus to the internuncial association cortical neurons. In the non-educated classes the

process of myelination of these neurons ceases much earlier in life, and as a consequence they do not attain the same degree of intellectuality, and, on the average, they have a smaller size of head.

The importance of myelination is also borne out by pathology, for it is a significant fact that in *multiple* or *insular sclerosis* of the brain and cord, the axis cylinders of the areas affected remain intact, whilst the myelin sheaths are destroyed. The disturbances of co-ordination accompanying this condition may, therefore, be an expression of a loss of insulated conduction.

CHAPTER XXXVI

NERVE IMPULSE

What Is Nerve Energy? Just as the physicist uses the term "gravity" to denote a force which he can measure, and the influences of which he can observe, but of whose nature he knows little or nothing, so does the neurologist employ the term "nerve impulse or nerve energy" to denote a phenomenon of which he knows little beyond its observable effects in health and disease.

As is well known the now generally accepted neuron doctrine of Waldeyer supposes that every neuron is anatomically quite distinct and separate from every other neuron, and that physiological connection between the neurons is brought about by contiguity, and not by continuity, of nerve substance. The nervous system is, therefore, made up of many millions of anatomically independent units combined physiologically into arcs, and separated from each other by intervals termed *synapses* or *neuro-synapses*. When any neuron is stimulated by the stimulus to which it is designed to react, a change takes place in the neuron, the nature of which is unknown, but is usually believed to be chemical, physical, physico-chemical or electrical, but as a result of this change "energy is developed within the nervous system." (Hill.) Any neuron so stimulated, must, in accordance with its combination with other neurons in arcs, discharge this energy or impulse on to the next neuron or neurons in the arc, arousing them to energy, and to do so, the neuro-synapse must be crossed. The latter is, therefore, a very important feature of the mechanism of the nervous system.

The nature of the impulse aroused by stimulation of a neuron has always aroused the deepest interest amongst

physiologists. Its existence is admitted though its nature is not understood, and it has been variously termed the "nerve principle, the nerve energy, the nerve force, and the nerve impulse." Dercum thinks it is electrical. He says "certainly the inference seems justifiable that all nervous transmission, in fact, all nervous activity, is electrical," though many authorities think otherwise. Dercum adds, "the interpretation of nervous transmission as electrical lends an added significance to the synapses. The latter have all the force and value of the Pupin inductance coil, for they both reinforce and facilitate transmission; and just as in the case of the Pupin inductance coil inserted in the telephone wire, the presence of the synapse in the nervous pathways of vertebrates results in an enormous economy of energy."

Bayliss is of opinion that the cell-body of a neuron may act as an agency for reinforcing impulses which might be too weak to set up a disturbance in a fresh neuron, so it is obvious that nerve impulse or nerve energy—whatever its nature—must be admitted. As Harris says, "those who are in the habit of dealing with the problems of the organism as a whole . . . constantly make use of this conception, for they find it impossible to make progress without it."

In the previous chapter it has been shown that many million neurons in the human body are constantly being stimulated, and are, therefore, as constantly transmitting nerve impulses centrally. Such receptor impulses must either traverse the whole arc to which they belong, and so produce an immediate effect, or they must be arrested, that is, stored up, in some intermediately situated neurons, as within the cerebellar and cerebral cortices, which liberate the energy upon some future occasion, and so give rise to a delayed motor or effector reaction. As has been seen the whole structure of the cerebellar cortex proves it to be a storehouse for nerve energy. That the same applies to the cerebral cortex appears to be just as certain, and hence the explanation of memory, which is a storing up of previously transmitted nerve impulses.

What Are the Sources of Nerve Energy? Both physiolo-

gists and neurologists appear to agree in regarding the Nissl bodies as the source of the nerve energy displayed when a neuron is stimulated. For example, Hill says, "energy is developed within the nervous system and it appears to be the Nissl bodies which supply the energy transmitted along a nerve. They disappear in certain pathological conditions, and under the influence of certain drugs, and their disappearance is spoken of as *chromatolysis*." Harris is of the same opinion. He says "we seem justified in saying that the Nissl granules are the physico-chemical basis of nerve energy, and are energy-producing (or dynamogenic)." In fact, Harris's work on this subject is illuminating throughout and justifies the following lengthier extract:

"That the nucleus should produce the granules of Nissl in nerve cells is entirely in agreement with its functions in cells which are not nerve cells. Still further, the chemical composition of the nucleus of the nerve cell and of the granules of Nissl, is very similar; a high percentage of phosphorus characterises both. If the nervous system has been allowed to get into an underfed, poor condition, then high phosphorus (lecithin) feeding is good for it, just as, if a person is anæmic, more iron than is normally present in food is good for her."

In ascribing the sources of nerve energy to the Nissl granules in accordance with physiological opinion it must not be forgotten that Nissl granules have not been observed in living nerve tissue. They have only been seen in the dead tissue after suitable staining, but there is no question that the appearances presented differ very materially according as to whether the stained tissue is from a nerve cell which has been experimentally exhausted prior to death, or from a fresh neuron.

Chromatolysis and Its Effects on the Mind. To these changes in the Nissl bodies, the results of nerve fatigue, the term *chromatolysis* has been applied by Marinesco. The histological appearances of a normal and a chromatolysed neuron cell body are well known and are figured in almost every text-book. The results of chromatolysis as regards nerve



FIG. 122.

FIG. 122. TO SHOW CHROMATOLYSIS.

(See illustration opposite)

1. Pyramidal cell of a dog after ligation of two carotids, one vertebral and one subclavian. Great swelling of the nuclei; advanced chromatolysis most marked at the periphery of the cell.

2. Pyramidal cell with diffuse staining from a cat after ligation of four cerebral arteries.

3. Anterior horn cell of spinal cord from a guinea-pig which died forty-five hours after injection of 0.2 mg. of abrus-globin. All the cells showed this diffuse staining and absence of Nissl granules.

4. Section of the spinal cord of a case of Congo sickness with hyperpyrexia, in which the temperature reached 109° F. prior to death. The whole of the cells throughout the central nervous system showed a diffuse homogeneous dull staining. The Nissl granules had entirely disappeared from the processes and the body of the cell and the stainable substance had a dust-like appearance. The processes are unusually distinct, the nucleus is clear and swollen, faintly stained, and the nucleolus deeply stained. (From: Craig, "Psychological Medicine.")

phenomena generally and mind in particular, do not, however, appear to be as widely recognised as they should be. It is known, for example, that various poisons, which affect the nervous system, have a pronounced effect in causing chromatolysis, and this also applies to toxins, the products of disease. A perfectly normal person, that is, normal as regards numbers and modes of connection of cortical neurons, will have his mentality impaired if he breathes, for too prolonged a period, an atmosphere surcharged with carbonic acid gas, or if he suffers from any of the microbic fevers. In either case the poison produces a transient chromatolysis of neurons, and intellectual function is correspondingly impaired. With the removal of the cause of the temporary neuronie chromatolysis, a process of repair will follow, and the intellectual powers will be restored. If it be not removed, the chromatolysis will proceed to the complete death of the neuron and the intellect will be correspondingly impaired.

It has been further established that cell-bodies of neurons examined shortly after death in *epileptic patients* in whom there has been a massive discharge of impulses prior to death, show a most extensive chromatolysis; and again chromatolysis is one of the earliest signs of *disuse atrophy*.

The actual physiological condition of the cell-body of the neuron is, therefore, a very important matter. If, from any cause whatsoever, extensive chromatolysis occurs in an individual of normal neuronie development and a corresponding mentality, it follows that fewer of those neurons will be capable of functioning correctly, and there will result an impaired intellectual activity.

Some Clinical Examples of Altered Nerve Energy. In *acute mania* there is often afforded an exhibition of abnormal muscular force which may be so violent as to call for restraint. The maniac can at times perform feats of strength which are astounding and far beyond his ordinary muscular strength. To suppose that this aberrant action is purely muscular is erroneous. The acute maniac is usually weaker and not stronger, and the apparent strength is due to nerve impulses

passing straight through the receptor-effector arcs, instead of being dissipated and arrested in the many internuncial neurons of the cortex. Such attacks of violence are often followed by periods of exhaustion.

In *acute melancholia*, on the other hand, there is an almost complete lack of energy. The nervous system is supremely depressed; the individual can hardly be prevailed upon to make any exertion at all. Atony and asthenia are its features, and this lack of neuronie energy is obvious in almost every symptom displayed by the melancholic.

This same lack of adequate nerve energy is also strikingly displayed by *mentally defective children (primary amentia)*. Such children almost invariably record an unusually low reading with the spirometer and dynamometer, much lower, in fact, than the normal child of the same age, and the cerebral ament does so, when his general physical development is at par or even higher. Being deficient in numbers of cortical neurons, there appears to be a corresponding diminution of energy developed in the nervous system, which is reflected in the diminished work accomplished by the muscles of respiration and grip. To the inexperienced in the ways and reactions of the mentally defective child, it comes as a surprise to see an apparently normally developed boy or girl fail so badly and so frequently at such simple physical tests, but the fact remains that it is so, and has been confirmed by practically every observer who has used these physical tests as part of his diagnosis chart in the detection of cerebral amentia. It seems to lead, once again, to the inevitable conclusion that a lack of neurons is associated with a diminished output of nerve energy.

A General Summary. If all this be summed up it appears to be reasonable to conclude:

1. That, whilst the nature of nerve energy does not appear to be accurately known, its existence must be admitted.

2. That its source is the chromatophilic substances known as Nissl bodies, which, in their turn, are products of the cell nucleus.

3. That the sum of the nerve energy—if such an expression be permissible—differs in accordance with the numbers of neurons and the physiological condition of those neurons.

4. That the energy displayed by the nervous system will be appreciably diminished in many abnormal conditions, as also in many minor states of ill-health, because of the interference with the neurons.

CHAPTER XXXVII

SLEEP, DREAMS, AND EMOTIONS

Sleep. Whilst there is no single theory which satisfactorily explains the phenomena of sleep, there are, nevertheless, certain well-established facts. It is not, therefore, proposed to enter here into any discussion of the theories and ingenious experiments which have been devised to discover the nature of sleep, but rather to refer to a few of the established facts, particularly in so far as they concern the thesis of the present work, which is, that neurons in combinations, are the physical instruments of mind.

Sleep is a partial or complete loss of consciousness, attended by a temporary loss of voluntary movement, and related to a cessation of, or at least a diminution in, the transmission, centrally, of receptor impulses. Clearly, therefore, these phenomena denote that certain cortical neurons are not functioning at the moment, and it is practically certain that this cessation of activity chiefly affects the pyramidal cells of the supra-granular cortex.

The performance of an effector action during sleep, such as the brushing away of a fly with the hand during physiological unconsciousness, shows (1) that impulses still pass into the brain from extero-ceptive and proprio-ceptive sources, and are capable of producing a purposeful reflex effector action; and (2) that all nerve cells do not go to sleep. Many of the neurons in the lower centres and the spinal cord never "go to sleep" at all, during the whole of life, as is evidenced by the fact that respiration and circulation are carried on continuously. It is true that such nerve centres have their activities lessened during sleep, but are never totally arrested, as is consciousness. It is, therefore, quite certain that, even

during sleep, many entero-ceptive impulses from viscera, and proprio-ceptive impulses from locomotory organs, continue to be poured in to the central nervous system, though their streams are certainly lessened, and may still produce purposeful reflex effector and unconscious actions.

Bayliss says, "the difference between spinal reflexes (segmented) and those in which the higher centres, and especially the cerebral cortex (supra-segmental) take part is the regularity of the former and the ease with which the latter are modified or abolished by events in other parts of the central nervous system. For this reason, Pavlov calls the former *unconditioned*, and the latter, *conditioned reflexes*. . . . The production of a conditioned reflex may be expressed in one way by saying that the reflex arc has taken on a new afferent neuron. But it must be remembered that the connection with this neuron is very easily broken or inhibited, and is modifiable in various ways. . . . If the cerebral cortex is completely removed, no conditioned reflexes can be formed at all."

During sleep many of the cortical cells, especially those of the supra-granular layer, are so removed from active participation in, or control over, many neuronie pathways, and it follows that there is, or may be, disordered and uncontrolled mental function, which is peculiarly manifest in the disordered dreams and nightmares to which the higher animals, particularly man—in whom there are supra-granular additions to the cerebral cortex—are liable. If Bayliss's statement just quoted, that, in the production of a conditioned reflex, the arc has taken on a new afferent neuron, be modified to read, "has absorbed a new series of granular cortical neurons into the arc," it will be observed that it fits in perfectly with what has already been said as to the functions of such cells as storehouses of memory. During sleep many of these are cut out of their respective arcs, or are wrongly absorbed in others, and hence dreams, when they occur, are disordered and undisciplined.

It is further a well-established physiological fact that all parts of the cortical cells do not fall asleep—that is, cease

functioning—or wake—that is, resume functioning—at the same instant. Response to sound sensations are the last to go, and the first to return. In healthy sleep the parts of the brain most active during the day should rest most profoundly during the night, and the onset of sleep will be favoured by muscular and mental fatigue, and the withdrawal of most stimuli of the extero-ceptive nervous mechanism, especially sound and light, and, in the case of the latter, Nature has provided an apparatus, the eyelid, to cut off the incoming extero-ceptive stimuli.

Baudouin, a modern lay exponent of suggestion and auto-suggestion, appears to ignore, or at least not to be familiar with, the most elementary physiological evidence. He states that sleep is very ready to obey suggestion, and that by auto-suggestion we shall be able to go to sleep almost instantaneously, prescribe the exact hour of waking, and prohibit nightmares. Not only does this modern apostle of Suggestion ignore the physical basis of mind, but he is also prepared to defy the more obvious physical imperfections of the body, for he goes on that “without any other treatment than auto-suggestion you can cure pimples, warts, varicose ulcers, and eczema.”

To prohibit nightmare without cutting off *all* incoming entero-ceptive, proprio-ceptive, and extero-ceptive impulses—that is, to kill the patient—is a physical impossibility. Nor is it possible to prevent nerve cells previously charged with such impulses from functioning during sleep.

Dreams. Nor does it appear that the purely psychological interpretation of dreams by the disciples of the Freudian school is based upon any surer evidence than is, apparently, their psychotherapy. In fact both the diagnosis and the treatment of this school of thought appear to be based on hypotheses advanced in defiance of all evidence—medical, neurological, and physiological. Lay, for example, says, “not satisfied with the materialistic interpretations put upon dreams by Freud, Jung thinks that they have not merely a retrospective meaning, but have a meaning for the present

and a value for the future. Freud is criticised by Jung for tracing too much of the dream back to the period of infancy, and to excessively sexual causes. . . . Jung, therefore, sees in the dream not only a psychic product absolutely determined by preceding causes in the strictly scientific sense of to-day, but regards the dream as an inspiration towards a higher form of intellectual and spiritual life."

Neurologically, it is quite impossible for a dream to be "an inspiration towards a higher form of intellectual and spiritual life," because it is compounded only of previous experiences, not future ones; nor are all dreams inspired by sexual causes, because the sexual organs form only a fraction of the many sources of nerve impulses which are continually being transmitted to the brain during both wakeful hours and sleep.

The dreams of healthy sleep are frequently of the past, or of a fantastic commingling of remotely past, with recently past events, and are quite obviously compounded of receptor impulses coming in at the actual moment of the dream from entero-ceptive and proprio-ceptive sources, and to a lesser extent, of extero-ceptive impulses, and of those which have previously been stored up in cortical neurons, as the result of stimuli received at long antecedent dates. That they are of a fantastic nature is obviously due to the fact that sleep chiefly affects the cells of the supra-granular layer, and thereby removes all control over other neuronic pathways, allowing the incoming impulses to run riot, as it were, over a number of uncorrelated neurons.

An indigestible meal shortly *before* sleep may produce irregular contractions of the stomach *during* sleep. The impulses aroused by these contractions are transmitted to the central nervous system through entero-ceptive routes and may stimulate some of the cortical cells—the conditioned reflex is broken—and there may follow sleeplessness, disordered mental function (dreams) or nightmare, according to the energy aroused by the gastric contractions and the numbers of cortical neurons which have gone to sleep. The dreams so aroused will necessarily be a grotesque commingling

of previous receptor impulses. Dreams which are currently believed to have foretold coming events have no real evidence behind them. They gain credence from hearsay gossip, and that complete lack of appreciation of the value of evidence which is so characteristic of everyday life.

Similarly, a distended seminal vesicle or a distended gall bladder may cause the passage of entero-ceptive nerve impulses to be passed into the brain during sleep, thereby stimulating some cortical cells to function in an irregular complex of neuronie arcs, and producing disordered mental activity in the form of fantastic dreams.

The following authentic dream illustrates the influence of too powerful proprio-ceptive stimuli producing disordered mental phantasy during sleep. A patient suffered from a particularly bad nightmare. He dreamt he was being crushed between a railway train and the girders of an iron bridge. The effector responses to the proprio-ceptive stimuli were so pronounced, even to shouting, as to arouse the household. It was then found that the patient's right heel had been caught between the spring mattress and the woodwork of the bed, and the pressure had been sufficiently severe to arouse pain. Here the dream is primarily aroused by a commingling of proprio-ceptive and extero-ceptive impulses from the abnormal pressure on the skin, muscles, tendons, etc., of the foot, which stimulated an irregular number of cortical neurons previously charged with extero-ceptive and other impulses aroused, in the past, by many railway journeys through and over bridges of all kinds, with the consequent result that there was irregular cortical action and reaction.

Again, a patient resident in Australia, dreamed that he was walking from Canonmills Bridge in Edinburgh towards Princes Street, with the intention of reaching the City Hospital. Somewhere in the vicinity of Henderson Row the dream apparently changed, and the dreamer thought he had stepped through an orifice in a rock face into a cave, at the bottom of which he stepped into icy cold water. At this moment he awoke, to find that the foot had become uncovered

and was extremely cold. Doubtless the Jung-Freudian school, who dispense with any study of the nervous system, would have interpreted this dream as a stepping back into the mother's womb, or the liquor amnii, or would have given some other equally fantastic travesty of the most simple physical phenomena. The real explanation of this dream is that, at one time, the patient actually lived in the neighbourhood of the first part of the dream. For some days before the dream his thoughts had been running strongly on Edinburgh and its Fever Hospital, on account of the recent death there of an old and valued friend. The particular district had been firmly fixed on the dreamer's wakeful mind because, on one occasion, many years ago, on returning late at night in the reverse direction he had stumbled on a night watchman reading Carlyle's "French Revolution"—an unusual episode which had thoroughly charged the appropriate cortical neurons. At this stage of the dream the foot had apparently become extremely cold from the exposure outside the bed-clothes, and the extero-ceptive impulses of cold from the exposed skin had blazed a new cortical path, and the dreamer's thoughts became switched over to a visit to a stalagmite show cave in Tasmania, the first of its kind he had seen. This cave was certainly wet and hence the perfectly simple and entirely harmless explanation of the dreamer falling into the water. Sex had nothing whatever to do with either the dream or its cause.

"Is it unfair," said the late Sir Clifford Allbutt, "to say that the interpretations given by psycho-analysis to the dreams of our modern Jacobs and Daniels are incredible nonsense?" Or that "popular psycho-analysis is false science; it has no units, no means of measurement, no controls, no precise definitions, no separation of objective and subjective evidence. . . . It is false to argue that the soul need not be tainted with foul suggestion." (Allbutt.)

The Emotions. The emotions can no more be studied apart from neurology and physiology than can any other phenomenon of the nervous system, for the same physical factor—the

neuronic arc—is at work throughout, and the incoming receptor impulses are again the elementary basis, the effector response being the visible sign.

An emotion is compounded of a number of sensations, and these sensations are derived from the activities of numerous receptor organs, and are transmitted centrally from muscles, both voluntary and involuntary, from sudorific, lacrimal, intestinal, and other glands, and from various extero-ceptive organs. These various incoming stimuli give rise to a number of involuntary and largely unconscious reactions, such as circulatory changes, local flushings and pallors, and so on. Expressed, therefore, in terms of neurology, it is clear that emotions are the result of incoming entero-ceptive, proprioceptive, and extero-ceptive impulses transmitted to the cerebral cortex, and dispersed through the innumerable granular and other internuncial neurons of the cortical association areas. Depending on the course pursued through the neuronic cortical arcs, there is either an immediate motor or effector response, or a delayed sensori-psycho-motor (Bolton) one at a future time. If the cortical path pursued be directly to the motor cortical area the effector response to the stimulus is immediate. If, on the other hand, the stimuli charge the internuncial neurons, the effector response is inhibited and may not manifest itself for some considerable time after the receipt of the stimulus.

If A insults B, and the latter gives A a black eye, the reaction to the stimuli has assumed the form of an immediate volitional motor response. Under other circumstances, where volitional movement has perforce to be inhibited, the effector response may assume the form of stimulation of some other effector organ, such as the lacrimal gland, and joy or fear may thus be followed by tears, that is to say, the lacrimal gland has been stimulated instead of a voluntary muscle. In children, where control or inhibition of the effector responses is not thoroughly established, consequent on the slower development of the inhibiting supra-granular cortex, cerebral emotion, that is a surcharge of cortical neurons by

intensive receptor impulses, is often attended by both increased glandular activity and volitional movement occurring simultaneously.

Control of the Emotions. It requires considerable effort to subdue a strong emotion, for emotions have a tendency to persist long after the ideas which aroused them have disappeared from consciousness. If an individual possess an insufficient number of inhibiting supra-granular cortical neurons, his emotions, that is, his incoming receptor impulses, will be under insufficient control, and some form of motor response—hysterical laughter, crying, disordered movement—may follow, whereas such emotions will be quite easily controlled by the individual with his average share of cortical neurons. If, however, the incoming receptor impulses be of an exceptionally powerful character, then even the latter may fail to achieve an adequate control. The gallery is usually more demonstrative than the stalls.

That some of the emotions persist long after the ideas which have aroused them have disappeared from consciousness is, of course, again capable of neurological explanation on the view that the incoming receptor impulses which have produced the emotions, have been sufficiently strong as to have surcharged many of the Golgi Type II cells, where they lie dormant until the appropriate stimulus comes along which again takes them up into the neuronie arc and so arouses memory.

Emotions, Passions, and Moods. Each emotion has its corresponding passion and mood, a *passion* being an intense emotion of short duration, and a *mood* a prolonged emotion of moderate intensity. The emotions, passions, and moods, may be correlated as follows:

EMOTIONS	PASSIONS	MOODS
Anger	Fury	Chagrin
Sorrow	Anguish	Gloom
Fear	Terror	Anxiety
Joy	Hilarity	Happiness

A study of the phylogeny of the vertebrate central nervous

system shows that lower vertebrates, those without a neopallial cortex, display certain primitive emotions, the seat of which must be the thalamo-striate brain, for the efficient reason that there is no other. How far crocodiles, frogs, and reptiles generally, display emotions is doubtful. Their motor or effector responses certainly differ according to the incoming receptor impulses from reproductive organs, or stomach, and the extero-ceptive impulses associated with them, such as the sight and smell of food, or the sight and smell of the female, but whether these effector responses are to be regarded as emotions is questionable. Two facts are, however, certain; that the effector responses are altered in accordance with the incoming receptor impulses, and that all are correlated in the thalamo-striate brain.

With the advent of the *mammal*, there has been a great increase in the number of neurons at the cephalic end of the neural tube, and a small, but well-developed neopallial cortex has made its appearance. This contains a fairly well-developed infra-granular cortex, and a feebly developed supra-granular cortex, but practically no association areas. With this increment in the numbers of cephalic supra-segmental neurons the expression of emotions would appear to synchronise. Domesticated animals, such as the dog, display emotions of fear and joy, and their reactions to certain receptor impulses would certainly lead man to believe, *from his own cerebral reactions*, that the dog is also capable of anger and sorrow. The higher mammals would, therefore, appear to feel and express the four simple emotions, and these, in their turn, may be sufficiently intense as to rise to the level of passions, but whether the dog has moods as well is very questionable.

Passing from the mammal, through the anthropoid ape, to *man*, there is a correspondingly increased expression of emotions, passions, and moods, and these always appear to be strictly correlated with an ever increasing number of cortical neurons, and the number and nature of the entero-ceptive, proprio-ceptive, and extero-ceptive impulses transmitted. It

is, therefore, only to be expected that the expression of emotions, passions, and moods, will be very different in the multi-neuronic genius from what it is in a person mentally defective from lack of neurons, and clinical practice and everyday experience abundantly prove the truth thereof. The man of genius is usually good tempered, and his emotions—though powerful when aroused—are transient and most frequently well restrained. His fits of anger are most commonly intense but evanescent, whereas the sub-normal individual often broods over largely imaginary ills and so establishes moods, because his receptor impulses pass much more continually over the same neuronic tracts. The deficiency of neurons limits the possible neuronic routes and so habits and moods are established.

No explanation of emotions, passions, and moods, or of their appropriate motor or effector responses or inhibitions can be accepted, which is not equally applicable to all living animals, in accordance with their position in the evolutionary scale and their nervous systems. Such explanation must be further applicable to all conditions of health and disease under which those emotions are displayed, and must be equally serviceable for the emotions of the sane, and the disordered ones of the insane. Psychological explanations which ignore the neurological factors concerned cannot but prove unsatisfactory. Those who endeavour to explain the phenomena of mind and its disorders without reference to the anatomy and physiology of the brain, almost invariably forget these essentials, and almost equally invariably introduce their own personality into that of others. One's own individuality is compounded of one's own receptor impulses, and it is frankly impossible to believe that some other individual has experienced precisely the like impulses. As Bayliss says, "Pavlov states that he was struck by the fact that when the physiologist leaves the study of the simpler parts of the central nervous system, which he has investigated by the observation of the reflexes, and proceeds to the higher parts, especially to the cerebral cortex, his methods suddenly

change. He gives up observation of the relation between external phenomena and the reaction of the organism to them and introduces psychological ideas, derived from his own internal consciousness." Howell, the American Physiologist, apparently agrees with Pavlov, for he says, cortical responses are, from a physiological standpoint, of the order of reflex actions, and they must be investigated and, if possible, explained from this point of view. All this leads once more to the only logical conclusion—that neurons are the physical instruments of mind, and that the phenomena of mind can only be correctly interpreted in terms of neurons and neuronic arcs.

Fatigue and Sleep. Sleep is necessary for the restoration of the fatigued neurons. Fatigue of the nervous system appears to be brought about in, at least, two ways. There is, *one*, the fatigue of excitation, resulting from the consumption of the materials of the protoplasm; and, *two*, the fatigue of depression, resulting from the accumulation of toxic products, as a result of neuronic activity. In either case, a fatigued nervous system will be an impaired system, and mental phenomena will be correspondingly altered. Sleep is the natural restorative, though how this is brought about is unknown. It may possibly be due to a cessation, or diminution, of incoming receptor stimuli, as a result of which the dendrons retract towards their cell-bodies, thus increasing the synaptic resistance, and tending to remove the neuron from participation in the impulses of its arc.

CHAPTER XXXVIII

CEREBRAL UNDERDEVELOPMENT OR AMENTIA

Definition of the Term "Amentia." By amentia is here meant an underdevelopment of the cortical neurons from any cause whatsoever, and in consequence of which the individual is unable to react to his environment in the manner regarded as normal by standards of normality.

Tredgold defines amentia "as a state of restricted potentiality for, or arrest of, cerebral development, in consequence of which the person affected is incapable at maturity of so adapting himself to his environment or to the requirements of the community as to maintain existence independently of external support."

But arrested cerebral development connotes a good deal more than a mere inability "to maintain existence independently of external support." It merges into the lunacies, the inefficiencies of everyday social life, crime, and prostitution, and it is, therefore, essential to take the wider view, which has been so admirably expressed by Professor Shaw Bolton.

Bolton on Amentia. "I employ the term 'amentia' to connote in the widest sense the mental condition of patients suffering from deficient neuronie development. . . . The types of mental disease with which I am about to deal agree, from the aspect of general histology, in possessing a subnormal development of the cortex cerebri which, except in the severer grades, is limited to the pyramidal or outer cell-lamina (supra-granular) of the cortex; and from that of morbid anatomy, in possessing an average brain-weight which is below that of the normal adult average, in association with normal cerebral membranes, vessels, and intra-cranial fluid. The

whole group of cases therefore comes under the heading of subnormal cerebral development."

Ontogenetic Development of the Neuron. In order to understand the nature of the underdevelopment of the cortical neurons in amentia, it is necessary to set out the normal process which should be followed.

It has already been shown (page 52) that the essential feature in the development of the embryonic neural tube into the central nervous system consists in the conversion of the

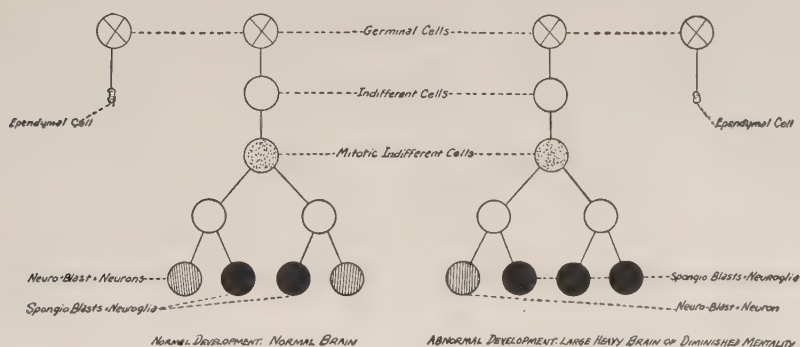


FIG. 123.—A sheme modified from Keibel and Mall to show how differences in the development of the neuroblasts and spongioblasts may affect both the structure and functions of the adult brain.

original single layer of cuboidal ectoderm cells into a thick wall whose elements are arranged in the form of three definite layers or zones, and that from the germinal cells are derived the indifferent cells of the mantle layer, which, in their turn, give rise to the spongioblasts and neuroblasts. This differentiation into neuroblasts (embryonic neurons) and spongioblasts (embryonic neuroglial cells) does not occur in all cells simultaneously, some cells being more precocious than others. In general, the spongioblasts develop somewhat in advance of the neuroblasts, and there may even be a fairly complete spongioblastic framework with but few neuroblasts. (Keibel and Mall.) It is thus obvious that, from the very earliest stages of the development of the central nervous system, there

is an inequality of spongioblasts or non-nervous cells, and neuroblasts. This inequality may persist into adult life and results in alterations in the numbers of neurons, and thus amentia is, in most cases, just as much an error of development, as are hare-lip, or club-foot. Between the human microcephalic idiot and the multi-neuronic big-headed type of genius the differences are so pronounced as to be obvious even to the most inobservant. The *post-mortem differences* reveal themselves in the size and weight of the brain. The differences in the *mental reactions* are equally striking and prove the formula—no neuron, no mind.

It is important to remember these developmental differences between spongioblastic and neuroblastic tissue, because a heavy brain weight is not necessarily a concomitant of genius. The extra weight and size may be due to spongioblastic overdevelopment, that is, excess of neuroglia, hence the large heavy brain of only ordinary, or even deficient, intelligence—an anatomical fact which is almost invariably ignored by those who endeavour, vainly, to correlate size of head with intelligence. Similarly a normal or over-neuroblastic development, with a diminished development of spongioblasts may result, though apparently much less frequently, in the small brain and head of average, or even high, intelligence, which again discounts the value of researches endeavouring to establish a relationship between size of head and intelligence.

Mierzejewski has formed the opinion that the basis of every anatomical lesion in the idiot's brain is a developmental deficiency in the nerve tissue, that is, neuroblastic underdevelopment.

Hunter found that in cases of hypertrophy of the brain the enlargement was generally due to an increase in the neuroglia, that is, spongioblastic overdevelopment, whilst Hewat, in an examination of the brains of epileptic children found a neuroglial overgrowth as a characteristic appearance, with an irregular arrangement and imperfect development of the brain cells.

It is thus clear that human individuals, even from before birth, differ very profoundly in the numbers of cortical neurons, or their potentialities, neuroblasts. The difference in numbers of such cortical neurons in the microcephalic idiot and the genius run into many millions, and between these extremes come the innumerable mental types which collectively form humanity.

The Microscopic Evidence of Cerebral Amentia. But the majority of the cases of cerebral amentia do not fall into the

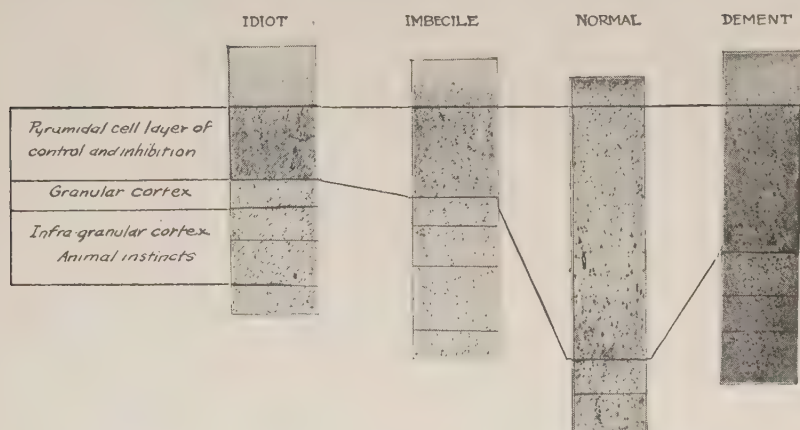


FIG. 124.—Microphotographs of the cerebral cortices of the idiot, imbecile, normal and dement to show the differences in the micrometric thickness and numbers of cells in the supragranular cortex in the human types illustrated. From J. Shaw-Bolton. See pages 366, 370, 375, 422, 493.

category of macroscopic lesions visible to the naked eye. The brain cells are so minute as to require magnification for their examination. It has not yet become the routine practice of the pathologist to make even a micrometric examination of the thickness of the cerebral cortex, let alone a microscopic examination of the cells themselves, and consequently the underlying cause of amentia escapes recognition. Attention may, therefore, be directed to the results attained by those who have made such examinations.

Sir Frederick Mott says in idiots who are incapable of articulate expression, millions of cells are arrested in their develop-

ment, and there is then a condition of amentia or absence of mind. He adds that this developmental failure chiefly affects the supra-granular layer of pyramids.

Tredgold says, "as compared with the nerve cells of the healthy brain, those of the ament are characterised by the following conditions: (1) numerical deficiency; (2) irregular development; (3) imperfect development of individual cells; and on the whole it may be stated that the amount of change discoverable by the microscope is directly proportionate to the degree of mental deficiency present during life." Referring to numerical deficiency of cortical cells, Tredgold further adds, "in many cases this paucity of cells produces a decrease in the thickness of the cortical grey matter, which is obvious to the naked eye."

Hammarberg and Ellis both come to the same conclusion, namely, that cerebral amentia is always associated with a deficiency of cortical neurons.

There is thus a sufficiency of microscopic evidence to prove the point that amentia is due to underdevelopment of the brain, and that the condition results in a diminution of the cortical neurons, particularly those of the pyramidal supra-granular layer, whose functions are those of inhibition and control.

A General Fallacy. It is quite commonly supposed, even by members of the medical profession, that amentia only includes idiots and imbeciles and those other grosser physical types, such as cretins and the like, which are quite easily recognisable by everyone. All other forms are apparently regarded as being merely "backward" and the parents are assured that the child "will grow out of it." It is exactly the unrecognised cerebral ament who is the dangerous social type, and of whom there are far more outside Institutions than in them. Bolton's work has quite definitely closed this gap between the gross ament (idiot and imbecile) and the normal, and it is essential, if the problem of amentia is to be understood and grappled with, that his observations should be more fully known than is apparently the case.

What Is Cerebral Amentia? "The group of cases classed under the heading 'amentia' thus includes not only idiots and imbeciles, but also a large number of cases which exhibit a milder degree of cerebral underdevelopment and of mental deficiency than the imbecile and form the connecting link between the mildest type of imbecile (the mental defective of the non-alienist) on the one hand, and the ordinary 'sane' individual of average intelligence and mental stability on the other. This group of cases, termed by me, 'high grade amentia' *closes a recognised but hitherto unfilled gap* between morbid and normal psychology, and makes it possible to reduce the subject of mental alienation into a coherent system, which on the one side of the normal includes all types possessing sub-normal neuronic development under the term 'amentia,' and on the other side of the normal all cases suffering from deficient neuronic durability with resulting dissolution under the term *dementia.*" (Bolton.)

Low Grade Amentia. In this clinical division are placed, by Bolton, those cases commonly known as idiots, imbeciles, and mental defectives of various degrees and types, either with or without epilepsy. Bolton thinks that, from a clinical standpoint, the term "low grade ament" is better than either "idiot" or "imbecile," which have always been unsatisfactory. An extensive clinical experience has convinced me of the wisdom of Bolton's classification, and I am accustomed to return this class of case as a low grade ament of the imbecile, idiot, or stable type, as the case may be. This is the class of case covered by Tredgold's definition as "incapable at maturity of so adapting himself to his environment or to the requirements of the community as to maintain existence independently of external support," but as stated on page 490 it does not nearly exhaust the field of cerebral amentia.

High Grade Amentia. Under this clinical division Bolton includes a number of cases which frequently find their way into mental hospitals, as well as many others who remain unsuspected in the community, except in so far as their disordered anti-social reactions arouse the suspicions of the

expert. This class frequently figures in the law and criminal courts, but is seldom submitted to that careful medical, physical, and mental examination which is so essential both for the welfare of the individual and the community. This group is, therefore, a large one, and includes moral, unstable and excited cases, cranks, asylum curiosities, recurrent cases of all types, hysteria, epileptic insanity, true paranoia and allied conditions. It must not be thought, however, that high grade amentia includes only thinly disguised asylum cases, because this clinical division also comprises many others who show no signs or symptoms warranting certification and usually pass quite unsuspected, unless *very special methods of diagnosis are employed*. Here, therefore, are included many criminals, thieves, prostitutes, ne'er do weels, anti-social cranks and quacks, and inefficient in all classes of life. This is the really dangerous form of cerebral amentia and is the very one which most frequently passess unnoticed.

All these cases of high grade amentia have certain *common physical features*. They all suffer from a more or less marked underdevelopment—or, in some cases, irregular development—of the cerebral cortex, with a comparative absence of intracranial morbid appearances. They are almost all developmental in origin. They are almost all deficient in the controlling pyramidal cells of the supra-granular cortical layer, and they thus almost all react to the environment on the more nearly animal basis of stealing, with abnormal sexual proclivities after, or sometimes before—dependent on the environment—the age of puberty. Further, many of these high grade aments depart so far from the normal reactions of the normal man, as to leave grave doubts in the minds of those not specially skilled in the diagnosis of the amentias, as to their sanity. Hence many of the debates in the Law Courts on this very point. The individual is not insane in the legal acceptance of the word, but, on the other hand, is not sufficiently normal as to be loose in the community.

Periods of Stress in the Life of the High Grade Ament.

The high grade ament being underdeveloped neuronically is liable to break down at certain periods of life under the stresses and strains inseparable from the daily struggle for existence. He frequently shows, for example, evidences of abnormal psychic processes at, or near, the age of puberty, that is, coincident with the incoming of new, strange, and powerful enteroceptive stimuli from the sexual organs. In one case, seen by the author, at the request of the Crown Law Authorities of the State of Victoria, a boy, aged 16 years, had murdered and mutilated his brother aged 8. He was a high grade ament of the stupid morose type and his aberration was certainly due to the cause here given.

Other breaking strains in the life of the high grade ament are the transference from school to employment, where the individual is suddenly faced with the necessity of earning his own living; any period of intense domestic squabble or emotion; the period of sexual involution; religious revivals; financial worries and the like. In the female there are also illegitimate pregnancies; abnormal menstrual disorders; normal non-septic parturitions and so on. It is at such periods that the high grade ament of both sexes is liable, on account of the lack of sufficient cortical neurons, to break down mentally and is thus an early prospective victim of such disorders as hysteria, dementia præcox, neuroses of various kinds, and of psycho-neuroses.

Differentiation of the Types of Amentia. Regarded from the neuronc standpoint it must be distinctly understood that the difference between these broad clinical types of low and high grade amentia is one of degree only, and the gradations are so fine that it is often difficult to know where the one type gradually merges into the other. Rapidly improving clinical methods are, however, slowly, but surely, enabling a sufficiently skilled neurologist to differentiate between the grades, though the social treatment of these aments is hopelessly

inefficient, as some are confined in mental hospitals, others are imprisoned, whilst the large majority are at large, and being unable to react normally to the complex environment around them are the cause of suffering to themselves and to others and a financial burden on the community .

Again it is to be noted that a high grade ament may react normally in the one environment and not in another, and it is the first duty of the clinical mental specialist to ascertain what environment will best suit the case. The ament always regards himself as normal according to his own standard. If



FIG. 125.—Camera lucida drawings of the supragranular cortices of a normal brain and that of a murderer to show that physical differences in structure underlie social reactions. After Wilson. See pages 368, 370, 375, 493, 499.

he be lacking in supra-granular pyramidal cells of control and inhibition he may, always given the environment, react on the animal basis of acquisition, that is, he may steal, commit crimes, and gratify his sexual lust whenever possible. According to his own standard he will regard these actions as normal, and he is thus frequently unable to understand morals or ethics. He is also much more apt to break down both earlier and more frequently than the normal individual and thus finds his way into a mental hospital, where dissolution of the neurons or dementia soon occurs and the ament passes over into a condition of dementia præcox.

Correlation of the Clinical Types of Amentia with the Underlying Histological Condition of the Cerebral Cortex. From the evidence already adduced it is now possible to correlate the general histological condition of the cerebral cortex with the clinical phenomena.

CLINICAL TYPES

Low grade amentia.

Idiots.

Imbeciles.

Mental defectives.

High grade amentia.

Morons.

Moral, unstable, and excited cases, together with cranks and asylum curiosities.

Psychopaths.

Recurrent cases of all types, hysteria, epileptic insanity, true paranoia and allied cases.

HISTOLOGICAL CONDITION

Deficiency of cortical neurons in both the infra-granular and supra-granular layers of practically all portions of the cortex. The higher the clinical type the less the neuronie deficiency.

Deficiency of neurons chiefly found in the supra-granular cortex of the prefrontal region.

Deficiency of neurons in some portions only of the supra-granular cortex, with excess in others.

Amentia plus dementia.

The essential basis of amentia is thus seen to be an imperfect or arrested development of the cerebral neurons, and the reactions to the environment vary accordingly. As Bolton says, the amentias are "the greatest of the degeneracies."

CHAPTER XXXIX

CEREBRAL DISSOLUTION OR DEMENTIA

Definition of the Term "Dementia." The term dementia is here employed to denote an involution or dissolution of the cortical neurons, that is to say, local death or destruction of brain cells, and the process is a natural one which will inevitably occur in all human beings who live long enough. As thus defined and employed it is clear that dementia is just as much a normal process as is the occurrence of the menopause or the loss of the sexual power in the male.

Physiological Dementia. Unfortunately the fact that dementia is the ultimate fate of every human individual who lives beyond the allotted span of life—as it is only a question as to whether the somatic and sex cells perish before the highly specialised brain cells—is so perpetually lost sight of, that the occurrence of the condition is almost invariably regarded as a disease, whereas it is a perfectly normal process *after a certain age*, and should, therefore, only be regarded as pathological when it occurs at too early an age, and whilst that age must always be problematical, it may be inferred that dementia should not, as a physiological process, precede sexual involution. If it does there is probably some underlying cause, which it is not always easy to determine. It would, however, appear as though a premature destruction of cortical cells is peculiarly apt to occur in those in whom there is, from birth, an original shortage of properly developed cortical cells, that is, some previous degree of amentia. In these patients there is a *lack of durability of neurons*, hence the early dementia.

Regarded as a normal physiological process, and not as a disease, it would also appear to be certain that the onset of

dementia is delayed in the educated classes, and that it occurs earlier and proceeds more rapidly in cerebral aments than in normal individuals. The cause for these class differences is either the greater durability of the neuron hardened from constant use, or is due to the possibly better hereditary history of the more highly educated and educable sections of the community.

Pathological Dementia. On the other hand when dementia or destruction of cortical neurons occurs in young people, or in adults below the age of sexual involution, then dementia

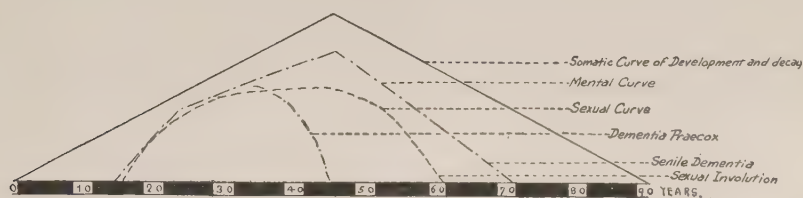


FIG. 126.—Curves illustrating the development and decline of the somatic, sexual and cerebral cells.

is undoubtedly pathological. It does not occur in all individuals at the same chronological age, and may commence at practically any period of life between puberty and old age. Whenever it occurs dementia is always followed by marked alterations in the behaviour, and these changes are strictly proportional, first, to the numbers of neurons originally possessed, and second, to the numbers destroyed.

As these cortical internuncial neurons are gradually removed, by destruction, from their normal cortical arcs, the manifestations of mind depart more and more, *not from normal*, but from those *originally displayed by the patient*. There will be loss of association of ideas, fixed ideas, delusions, hallucinations, and many of the other behavioural phenomena of the lunatic.

The Neurology of Dementia. Tredgold very aptly compares dementia, that is, mental defect occurring subsequently to mental development, to a state of bankruptcy, whilst the

person whose mind has never attained normal development may be looked upon as never having had a banking account.

Sir Frederick Mott says simple dementia or loss of mind may be associated with a limited destruction of the anatomical basis of mind, namely, the highest psychic level, and, the two lower levels being more or less intact, the habitual acquired sensori-motor reactions may remain and the individual may then behave as an automaton in response to environmental influences and bodily needs.

Under the term *dementia*, Bolton includes all cases which agree, from the psychic aspect, in the possession of a decreased or decreasing mental capacity, and from the physical, in the existence of a distinct and permanent loss of cortical substance in those regions of the cerebrum, which especially serve as a physical basis for the carrying on of voluntary psychic processes.

Whilst a large number of such cases are examples of natural involution of the cortical neurons, occurring at such individually diverse periods of life as are determined by their inherent capacity of resistance to the process of decay, in many, perhaps even in the majority of the cases falling into the group, both the actual point of time at which the process of dissolution commences, and also the extent and degree to which it proceeds, are largely influenced by extraneous factors. These consist, adds Bolton, of, one, the various influences which combine to produce the normal and relatively harmless environment of sane individuals, and, two, of more variable and accidental factors of, usually, a toxic or a nutritional nature. If the process of neuronc dissolution be one of normal involution, or if it be excited by permanently existing and progressive factors, for example, degeneration of cerebral vesicles, it continues more or less slowly until death occurs. If, however, it be excited by non-progressive, temporary, or removable causes, whether these belong to such extreme types as cerebral lesions, alcoholic excess, or puerperal toxæmia on the one hand, and what constitutes the normal "stress" to which all healthy cortical neurons are

subjected in a civilised community on the other, cessation of the causative influence may result in an arrest of the process of neuronie dissolution, and the patient may live for years in a practically stationary condition of mental enfeeblement.

Bolton thus employs the term *dementia* to connote, in the widest sense, the mental condition of patients who suffer from a permanent psychic disability due to neuronie degeneration following insufficient neuronie durability. Such cases exhibit naked-eye post-mortem morbid appearances which vary in severity according to the degree of dementia present. In the case of any apparent exceptions to this general statement, it can be demonstrated by histological methods that degenerative changes of an acute nature exist in the cortical neurons, particularly in those of the pyramidal supra-granular layer, and that these correspond in degree with the grade of dementia present.

It has already been shown that the cerebral ament is liable to break down, mentally, at certain "stress" periods of life. It is also at these great periods of life, puberty, maturity, the climacteric, and senility, that a primary involution of the neurons is most apt to occur, and there is thus often grafted on to the original developmental amentia, a dementia or actual destruction of the cortical cells, and the combination of both so profoundly disturbs the patient's relations to his environment as to cause him to be placed in a mental hospital. In all such cases it is clearly the most recently added evolutionary layers of the brain which will be first affected by the cellular destruction of dementia, that is, the pyramidal supra-granular cortex, because, having been recently added, it is in a state of instability.

Use of the Word "Dementia." The word "dementia" is frequently used, especially in asylum work, as though it were a special disease in itself, which it is not. "It is a state produced by dissolution and always denotes a former state of higher intelligence. Idiocy and imbecility are conditions of amentia due to failure of evolution, but in dementia there has been some amount of mental development which has



FIG. 127.—Section (B.) from the ascending frontal convolution, from a case of General Paralysis, showing distortion and diminution in the number of the pyramidal cells and irregularity of the cell layers as compared with a normal section (A.). There is an abundance of round nuclei which are the nuclei of necrotic cells and lymphocytes. Stained by Nissl method. Drawn by A. M. Kelley. (From: Craig, "Psychological Medicine.")

become degraded. It is clearly wrong to describe dementia as a distinct malady." (Maurice Craig.)

Amentia thus denotes a feeble mind due to lack of a sufficiency of properly developed cortical neurons. Dementia, on the other hand, is a state brought about by a destruction of cortical neurons, and thus again leads to a feeble mind, quite irrespective of the degree of intelligence previously possessed. That the ament is likely to develop dementia both earlier and more frequently than the normal individual is certain, and it appears to be equally certain that combinations of these two conditions are not uncommon in many individuals who are not in mental hospitals, but who pass for normal, and are thus responsible for much suffering in the social community, on account of the falsity of their misguided ideas.

It is also not improbable that the modern rate of increase in the insanities is due primarily to the fact that the high-grade ament is not able to stand up to the ever increasing demands of a complex civilisation. The environment is becoming altogether too severe for his defective neurons to withstand the strain. He breaks down, develops a precocious dementia, and thus swells the mental hospitals. Were the amentia diagnosed earlier, the individual could be placed, under suitable laws, under the simpler environment of a segregation home colony where he would be made happy and self-supporting.

CHAPTER XL

CEREBRAL AMENTIA AS A NOT UNCOMMON FACTOR IN MANY OF THE NEUROSES

Cerebral Underdevelopment and the Neuroses. Were a systematic microscopic examination made of the cortical cells of all patients who have died after having suffered from many of the neuroses and the so-called psycho-neuroses, it is very probable that amentia would be found to be the common underlying physical factor. It must not, however, be forgotten that these same neuroses may occur in perfectly normal individuals, from ill-health of the neurons, rather than from an insufficient development; that is, a transient chromatolysis, from which the patient recovers, may so reduce the functional activity of the cortical neurons, as to give rise to symptoms which simulate those of the neuroses. In either case the reactions to the environment will be altered, and if these alterations in the environmental reactions are sufficiently pronounced as to cause danger to the individual, or to others, the condition will be regarded as lunacy and certification will follow.

Abnormal Reactions to the Environment. Abnormal reactions to the environment, the more gross of which are usually regarded as lunacy, may be brought about in at least four ways.

One, as the result of developmental error. Here the insufficiency of cortical neurons is present from the outset. Such a condition is permanent and constitutes primary amentia. Provided the environment remains simple the individual may worry through, but it is practically certain that at some subsequent period of "stress" the individual will break down with a neurosis or certifiable form of lunacy.

Two, as a result of many post-natal diseases, such as syphilis, altered glandular secretions, toxæmias, etc., the normal conversion of immature brain cells into functional neurons may be arrested, and as the individual becomes older he becomes progressively and relatively under-neuroned. To this class belong most of the secondary amenias.

Three, as the result of a non-recoverable chromatolysis in an otherwise normal neuronie brain. Here the normal numbers of neurons have originally been present, but become impaired or even destroyed at a later date. If the causes of the chromatolysis be not removed, some, at least, of the cortical neurons will become permanently destroyed, and there will ensue disordered reactions to the environment, the extent of which will depend on the numbers of neurons destroyed. If, on the

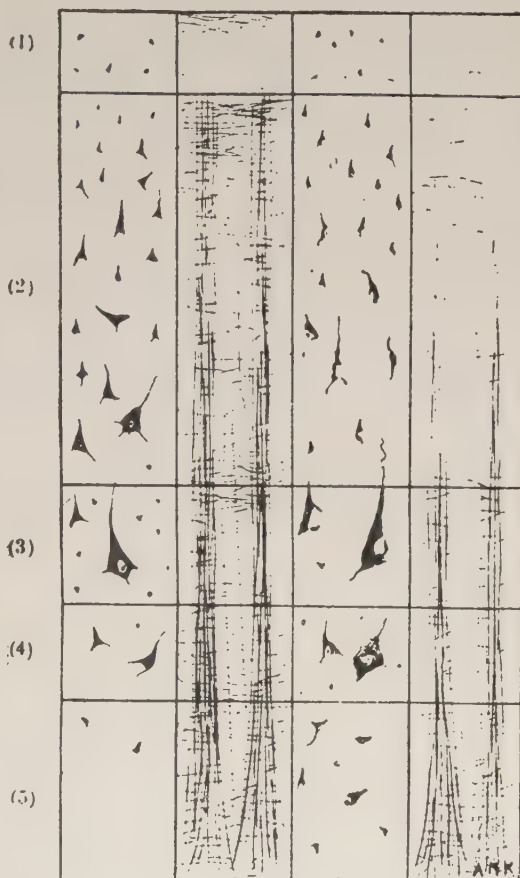


FIG. 128.—Types of lesions giving rise to deficient intellectual power. In amentia the deficiency is due to failure of development; in dementia, to atrophy of the cells (especially small pyramidal) previously present in the cortex (Mott). (From: Starling, "Principles of Human Physiology.")

other hand, the cause of the chromatolysis be removed before permanent destruction of the cortical neurons has taken place, there will be recovery.

Four, in those cases where the neurons are lacking in durability, from bad heredity or other developmental cause, there is likely to ensue a premature dementia, on account of the early death of the neurons, and some form of dementia præcox results.

Whatever the cause, the individual thus finds himself in a condition where there is an insufficiency of neurons to give normal reactions to the environment. He thus reacts abnormally to what is ordinarily a normal environment, or it may be that the abnormal environment, reacting on too few cortical neurons, causes the mental aberrations. Many of the so-called cases of shell shock probably belonged to this latter category.

Huntington's Chorea, Epilepsy, and Hysteria. Huntington's chorea, epilepsy, and hysteria would all appear to be examples of disordered reactions to the environment from cerebral insufficiency, that is, lack of normal numbers of cortical neurons.

In *Huntington's chorea* the mental state is one of progressive enfeeblement and depression. It may precede the motor symptoms, but usually follows them at varying periods. As the result of some carefully conducted post-mortem examinations Good and Kattwinkel found widespread degenerative cellular changes throughout the cortex, most marked, however, in the frontal regions, that is, in one of the very regions where cell shortage is most pronounced in amentia. Margulis, in two cases, found great proliferation of neuroglia throughout the brain and cord, and feels justified in calling the disease a congenital chronic degenerative gliosis. Huntington's chorea thus appears to have amentia as its original basal factor.

In many instances *epilepsy* is associated with morphological cellular changes in the cortex. In many more cases the anatomical basis still escapes detection—chiefly because it is not

looked for. But so commonly is epilepsy present in those physically or mentally defective, or those who come from neuropathic and psychopathic stock, that the clinical history alone is strongly suggestive of the close association of epilepsy with amentia. Post-mortem examinations, when sufficiently carefully made and including a microscopic examination of the cortex, are entirely confirmatory of the association of epilepsy with an underlying amentia. Clark and Trout describe widespread changes in the cortical cells, especially of the supra-granular layer, consisting of deformities, absence of chromatic substance, and swelling of the nucleoli with a tendency to loss of the nucleolus. Turner lays stress upon the apparent lack of full development of many cortical cells and the persistence of subcortical cells indicating imperfect differentiation and growth.

Janet, who has for years studied the *hysterias*, early contended that hysteria belongs to a group of mental diseases of cerebral insufficiency, and heredity is here just as prominent a factor as it is in the amentias. Hysterical patients usually belong to neuropathic families, that is, congenital and hereditary amentia seems to run through all. Clinically, hysteria appears to be characterised by the occurrence of too powerful or improper discharges of nerve energy through too few neurons.

In all these conditions, therefore, cerebral insufficiency or amentia appears to be the basal underlying factor.

Neurasthenia. It is impossible to study the clinical manifestations of neurasthenia without coming to the conclusion that, in most cases, there is an underlying cerebral insufficiency, and in others, a lowering, from some cause, of the vitality of the cortical neurons. In either case too great a strain thrown on an imperfectly constructed, or improperly functioning brain, may bring, in its train, a host of nerve symptoms, of which neurasthenia is the generic name.

If there be too few neurons, the excessive strain of modern social conditions rapidly induces, in such a nervous system, a chromatolysis with consequent nerve fatigue and irritability.

The same strain thrown upon a more richly endowed neuronic nervous system would not produce the same results, or, at all events, their manifestation would be much delayed. Here, therefore, the nature of the environment appears to be an important factor.

In the war the strains and stresses thrown upon the nervous system were much greater than in ordinary life, and in some cases, were infinitely greater than the nervous system was ever designed to withstand. Hence the under-developed neuronic nervous system was quite incapable of withstanding such stresses, under which it "wilted" and gave way, and the individual suffered from an exaggerated neurasthenia, commonly, but probably quite erroneously, called *shell shock*. This is not to be interpreted as meaning that all such cases occurred in cerebral aments. They did not. War conditions were such as to induce chromatolysis in perfectly normal nervous systems, and the phenomena of neurasthenia, or the still more exaggerated ones of shell shock are easily explicable in such cases. But, speaking generally, it is most probable that shell shock was, in the cerebral ament, more severe, more permanent, more intractable to treatment, and tended more readily to recur, than in those where the mental and motor disturbances were the result of a transient, but no less profound, chromatolysis, produced by fatigue, lack of food, and excessive emotional stimuli.

Every individual has his breaking-down point, that is, the point at which he will cease to react normally, and other things being equal, this point will be reached more rapidly in those with a subnormal central nervous system, such as that possessed by the ament. As Campbell Thomson says, "there are some persons whose nervous systems are so constituted that they quickly feel any undue stress, and are unable to adjust themselves adequately even to the average circumstances of daily life. Such people are in a more or less condition of neurasthenia, which varies according to their state of general health and to the surroundings in which they happen to be situated. On the other hand, those who possess

nervous systems of average, or greater than average, stability will only become neurasthenic from some unusual stress of mind or body." The first group is clearly under-neuroned. The second is not. But curiously enough the former condition is popularly termed "nervy," whereas it is really the exact converse—a lack of "nerves," that is, neurons, which is the basal condition.

To submit such a cerebrally insufficient nervous system, already staggering under a load greater than it can bear, to an intensive bombardment by the suggestion of psychoanalysis, does not appear reasonable or likely to produce any but the most disastrous results, especially if such a form of therapy suggests to the patient ideas of sex or perverted sex. The ideas of the cerebral ament are sufficiently perverted without any additional suggestions or additions thereto.

Psychasthenia. According to Maurice Craig "obsessions or compulsive ideas are the main clinical features of psychasthenia, and these may become so pronounced as to make it necessary for the person to be placed under care. Ill health tends to strengthen these obsessions and to render them more formidable."

In view of the almost complete absence of adequate pathological data it can only be inferred that if there is here not an underlying cerebral insufficiency, there must, at least, be a very irregular development and association of cortical neurons, so that nerve impulses tend to track the same series of neurons, thus leading to the obsessions and compulsive ideas. It would certainly appear, on clinical grounds, that psychasthenia has much in common with cerebral amentia. Both are frequently marked by signs of degeneracy; in both heredity plays an important part; in both chromatolysis induced by fatigues, excesses, traumatisms, infectious diseases, emotional strains, frights, general fears, grief, bereavement and the like appears to aggravate the condition, so that it is not improbable that a developmentally mal-constructed nervous system is the underlying factor.

Conclusion. From all this it appears that cerebral amentia

is a not uncommon underlying factor of many of the neuroses, and there seems to be corroborative histological evidence in support thereof. Closely associated with this cerebral insufficiency of neurons are the problems of chromatolysis and an irregular discharge of nerve energy, often over the wrong neuron arcs. It is not to be forgotten that the neuron is a delicate structure which is peculiarly susceptible to poisons of all kinds, and may have its functions grossly interfered with by many bodily changes, such as anæmia, toxins, altered glandular secretions or their lack, drugs, insufficiency of oxygen, and many others. Even the prolonged administration of an anæsthetic may, in the case of a patient with a tendency to amentia, seriously impair his subsequent mental reactions, and even result, though less frequently, in a temporary state of mania.

CHAPTER XLI

HEAD SIZE AS A DIAGNOSTIC INDICATION OF CEREBRAL INSUFFICIENCY

Correlation of Cerebral Amentia with Abnormal Head Size. That abnormal mental types tend to have abnormal heads has long been recognised, and the exceedingly small head of the microcephalic idiot is the extreme instance and proof of the doctrine. The pathological association between cerebral insufficiency and head size has, however, been largely lost sight of on account of the results of a series of scientific investigations undertaken some years ago to determine the correlation, if any, between size of head and intelligence. As no such correlation could be established *physiologically*, it was, perhaps, too hastily assumed that there was no *pathological* connection either, which is not the case. It is unquestionable that abnormal mental types *tend* to have abnormal heads, and it becomes, therefore, a diagnostic principle of some importance to determine, if possible, the extent and cause of this abnormality of head size, as well as its significance, because light is thus often thrown on the state of development of the cortical layers of the brain.

Almost every neuro-pathologist who has investigated the problem seems to be convinced of the pathological association between cerebral insufficiency and abnormal head size. Thus, Bolton states that amongst the stigmata of degeneracy displayed by the ament is often an abnormality of the skull. Tredgold also believes that the majority of aments present some abnormality in size or shape of cranium, though there is no particular type of skull characteristic of the condition. Church and Peterson also think that amongst the more impor

tant anatomical stigmata of degeneration to be noted in connection with the head are asymmetry and a variety of deformities. Amongst non-medical writers both Binet and Montessori have advocated head measurement in some form or another.

Head Measurement as an Aid to the Diagnosis of Cerebral Amentia. If head measurement and the calculation of the brain capacity is to be of any service in the diagnosis of cerebral insufficiency it is very necessary to understand both the procedure, and the object. As thus employed, it has nothing whatsoever to do with the determination of the patient's intelligence. It only seeks to ascertain exactly how far the patient departs, if at all, from the normal, and if there should be a pronounced departure, the neurological significance of the same. This, it will be noticed, is a very different procedure from attempting to determine the patient's intelligence from the size of his head, and is of very real value as an aid in the diagnosis of amentia, because it is in this very class of case that the departure from the normal is usually sufficiently pronounced as to be revealed by the procedure.

Technique of the Measurement of the Head. The technique is as follows:

Measure in millimetres the maximum length and breadth of the head by means of any standard callipers, and the maximum vertical height of the head from the ear-holes by means of any standard radiometer. The instruments employed by the author for these purposes are Flower's callipers for length and breadth, and Grey's radiometer for the height. From the resultant measurements the cubic capacity of the brain is calculated by means of Lee's formula, in accordance with the instructions given in the following chapter.

Brain Growth in the Normal Living Child. Prior to the publication by Berry and Porteus of their investigation into the cubic capacity of brain of 10,000 living boys and girls, nothing was known as to the rate of growth of the brain in the living subject, nor of the cubic capacity of the head of the

growing child. From their observations it appears that there is, first, a *pre-pubescent period*, which covers, roughly, the first eleven years of life. During this period brain growth proceeds more rapidly in girls than in boys, the respective percentages of total brain volume being 91.3% and 88.8%.

Second, there is a *resting phase* of about one year—the twelfth year—immediately preceding the onset of puberty. During this year brain growth is almost stationary in both sexes, and only increases by 0.6% in both boys and girls.

Third, there follows a period of two years—the thirteenth and fourteenth years—*coincident with puberty*, during which the brain increases by 3.4% in girls, and 2.2% in boys.

Last, comes a *post-pubescent period* of six or more years which takes the individual into adult life, and during which the brain should complete its growth, *but does not always do so*. If completed, it appears to increase by 4.7% in girls, and 8.4% in boys.

The fact mentioned by Bolton that the high-grade ament often shows signs of abnormal psychic processes at, or after puberty, is a most significant one, and becomes still more significant when read in association with these new facts relative to the rate of brain growth on the living subject. That these abnormal mental processes should manifest themselves just about that very period when there is a distinct slowing in the rate of brain growth, is a fact of the very greatest clinical significance. There can be no reasonable doubt that in many aments brain growth practically ceases at the period of puberty. The post-pubescent increment is not made and this clearly denotes that the supra-granular or controlling cortical layer does not, in the ament, keep pace with the sudden onset of sexual life, with the results that there will be, physically, a smaller head (other things being equal) and a lowered reaction to the environment, that is, a more nearly animal behaviour. When, therefore, as has actually been proved in the case of Deeming, and other Australian murderers, there is found an adult with only the head and brain

size of a normal 12 or 13 year old boy, there is afforded the strongest presumptive evidence that there has been an early arrest in the growth and development of the supra-granular cortex, with the results that there is a small head easily detectable by measurement, with abnormal social reactions consequent on the cerebral insufficiency in the controlling brain.

Determination of the Frontiers of Abnormality. If the calculation of the brain capacity from certain measurements of the head is to be of any value to the mental specialist, it is obviously of the first importance to know when the range of normality passes over into the potential abnormalities, and this is, perhaps, best accomplished clinically by the employment of Sir Francis Galton's *percentile system*.

As percentiles show the exact position occupied by any individual relative to other individuals of his own age and sex, they not only furnish an accurate method of determining the range of variation of the observations, but they also indicate how far the individual departs from the average of his class—represented by the median percentile of 50—and thus afford some prospective indication of the extent to which extremes from the mean are to be regarded as abnormal. As percentile tables are now very largely employed for comparative biological purposes, as well as for the determination of a patient's mental standing, it is of the first importance that they should be understood.

Explanation of the Use of Percentiles for Diagnostic Purposes. Let it be assumed that it is desired to investigate the stature of a large number of adult men by the percentile method. Every individual's stature would be recorded on a separate card. These cards would then be sorted out and arranged in order from the lowest to the highest. A scale, numbered 0, 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100, is prepared. The stature of the smallest adult is recorded opposite the zero percentile. The cards are then counted through for one-tenth of their number and the stature found on that par-

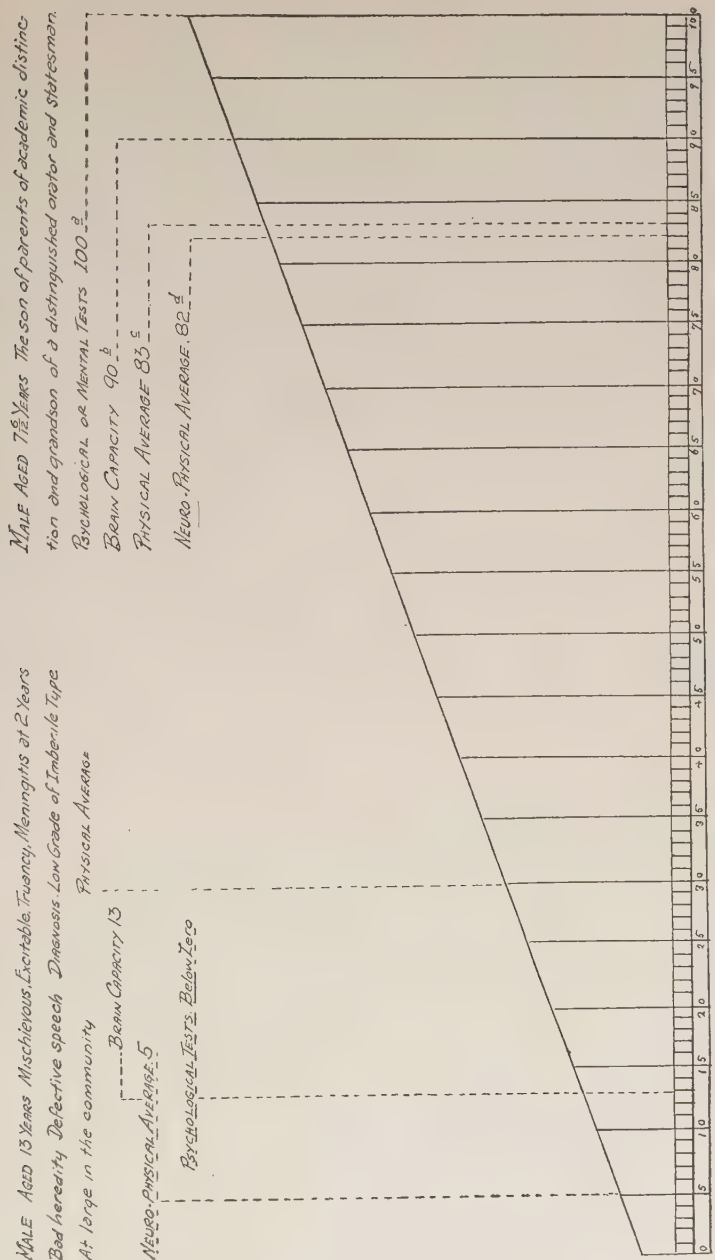


FIG. 129.—A graph to show how Sir Francis Galton's percentiles may be employed to determine ranges of variation and the frontiers of potential abnormality, with two contrasted clinical cases. See pages 516, 518, 527, 533, 537, 542, 548.

ticular individual's card is placed opposite the 10 of the scale, and so on right through the whole series until the last card is reached, which is that of the tallest man, whose stature is recorded opposite the 100 of the scale. *Provided a sufficient number of observations have been recorded*, running into several thousands, the median percentile (50) will give, without any calculations whatsoever, the average stature of the group under consideration. It is further obvious that the zero and 100 percentiles will give the statures of the smallest and tallest individuals in the series, that is, the range of the variation; that the dwarfs will fall below the 10 percentile, and the giants above the 90 percentile, and that the individuals whose stature comes between, say, the 15 and the 85 percentiles may provisionally be regarded as falling within the natural range of normal variation. The procedure is so simple, and so useful for all subsequent purposes of comparison, that it is a matter for regret that it is not more generally adopted by school medical officers and others when recording the weights and statures of large numbers of school children.

Application of the Percentile System to Size of Head and Brain. This percentile procedure, applied to size of head and cubic capacity of brain, forms the only accurate method of differentiating the unduly small heads from the unduly large heads, and leaves the mental clinician free to correlate the result with the rest of his clinical and mental examination. There is no question that from 50 to 75% of the unduly small heads, those falling below the 15 percentile, will subsequently be found to be suffering from cerebral insufficiency, and that about one in every four of the big heads, those above the 85 percentile, will prove to be of super-normal intelligence.

Correlation of Brain Weights, Cubic Capacity Percentiles, and Brain Structure. As all the cubic capacity brain percentiles have been fully worked out by Berry and Porteus on over 10,000 children and adolescents, it is now possible to correlate their results with previously recorded observations on brain weights, and cerebral construction (page 521).

The percentiles of the cubic capacity of brain given above are from a large group of University adolescents in the third decade of life. It will be noticed that there is a difference of nearly 400cc. between the highest and the lowest, and this difference is so pronounced as to make it certain that it has some physical explanation, and this explanation is clearly differences in brain cortical development. It is a striking and significant fact that the individual who occupies the zero position with the smallest cubic capacity of brain is 209cc. less than the average of his class, age, and group, and that, in head size, he is only the equal of a normal boy of between 8 and 9 years, and this, notwithstanding that his age, at the time of examination, was 22 years and 11 months. He was also found to have had a very remarkable anti-social history. As a boy he was at a large Public School where his educational work, until the age of puberty, presented no very remarkable features. Soon after the age of puberty he was expelled for gross sexual offences, was re-admitted, but again, and finally, expelled for the same offence. With the aid of a coach he managed to pass the by no means difficult entrance examination of a University, where he embarked, of all things, upon the study of Medicine. At the end of his first year he was rusticated for improper methods in his examinations. He then enlisted for war service and gave much trouble in his several camps for his earlier scholastic offences. He subsequently re-entered the University from which he had been expelled and, after several deplorable examination results, finally abandoned the study of Medicine, a profession upon which, had he ever entered it, he could only have brought discredit. It should surely require no further demonstration that this youth is a cerebral ament, and that his amentia has been revealed by head measurement, corroborated by his anti-social reactions, that his sexual behaviour is in accord with neurological findings as to the functions of the infra-granular cortex, and the lack of control over the same from an undeveloped supra-granular cortex. In this case the supra-granular cortex is obviously under-developed, and head measurement shows it.

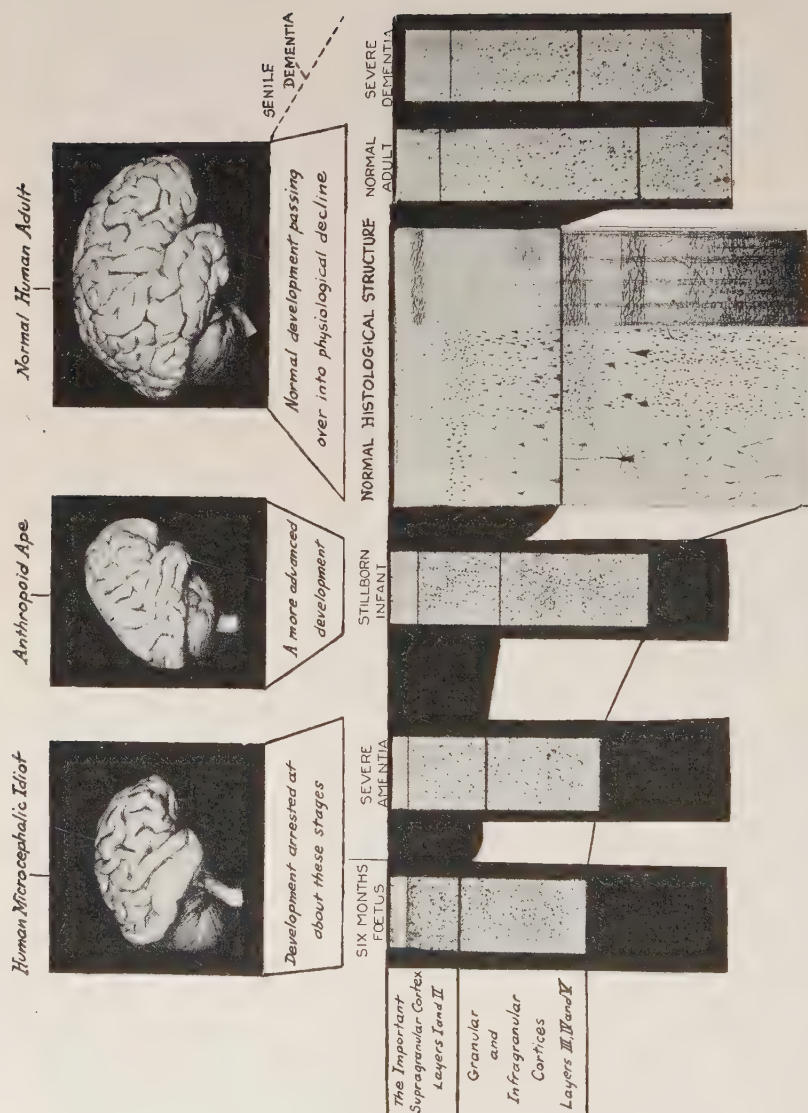


FIG. 130.—A series of photographs and microphotographs (the latter after Bolton) to show the correlation of the microscopic condition with the structural stage of development of the cerebral neurons. See pages 361, 368, 372, 376, 491, 493, 495, 500, 518, 524, 526.

BRAIN WEIGHTS	PERCENTILES	STRUCTURE
Low brain weight due to neuronie underdevelopment. Microcephals, small-headed aments, etc.	0. 1272cc.	Provided there be no compensatory increase in neuroglia, fluid, etc., the correlation holds good. It does so in 1 out of every 2 individuals, but with aments and neurotics, the correlation is higher.
	10. 1370cc.	
	20. 1411cc.	
	30. 1442cc.	
Those with a sufficiency of cortical neurons to give a normal reaction to normal environments. Average brain weight about 1335 grammes.	40. 1463cc.	
	50. 1481cc.	Line of normality.
	60. 1509cc.	
	70. 1528cc.	
	80. 1563cc.	
	90. 1589cc.	The high cubic capacity and big head may be due to neurons or neuroglia. It is impossible for head measurement to distinguish between them, but neurons and large size are more frequently correlated than neuroglia and large size.
Those who have more than the average number of neurons, <i>i.e.</i> , the multi-neuronie genius; or those who have more than the average amount of neuroglia, <i>i.e.</i> , the big-headed of ordinary or deficient intelligence.	100. 1669cc.	

In advocating the use of head measurement, the calculation therefrom of the patient's cubic capacity of brain, and the comparison of the result with the correct percentile table of the patient's age, sex, and group, in all cases of suspected mental aberration or nervous disorder, there need be no false illusions as to the possible demerits of the procedure. That it must frequently fail to give any information whatsoever is only too certain. On the other hand, there are so many cases of amentia where the method correlates highly with cortical neurology that there can be no question of the value of the procedure. Under no circumstances can head measurement differentiate, in the case of the big heads, between neuroglia, fluid, or neurons, but with the danger signal held out of possible potential abnormality, an expert should have but little difficulty in the final differentiation.

It is sometimes objected, though the objection can only arise from ignorance of neurological fact, that a difference of

a few micro-millimetres in the thickness of the cerebral cortex cannot produce a measurable difference in the size of the living head. The would-be critic forgets that the supra-granular cortex is composed of pyramidal neurons the axons of which all enter the white medullary centre of the brain, where they become medullated, and as Donaldson has shown, medullation is the chief source of increase in weight of the brain between birth and adolescence. As a difference of only a very few micro-millimetres in the thickness of the cortical layers means a difference of many million medullated axons it is obvious that the so-called "criticism" is not criticism at all, but is just another instance of that type of ignorance which so often mistakes itself for criticism.

Conclusions as to the Value of Head Measurement in the Diagnosis of Cerebral Insufficiency and Mental Abnormality. Head measurement, and the calculation therefrom of the cubic capacity of brain, is not a measure of intelligence, and should not be employed for that purpose. Intelligence cannot be measured, but mental reactions can.

As mental development is entirely dependent on numbers of fully developed neurons, striking deviation of brain and head size from the normal will tend to be associated with mental abnormality. When this deviation attains a certain sufficiently high degree it will be revealed by head measurement, and the calculation therefrom of brain size. One in every two aments—probably more—has an abnormally sized head, gross enough to be demonstrated by head measurement.

As such cases of striking deviation from the normal are due, in many cases, to developmental failure of the supra-granular cortex, that is, the layer of control, inhibition, and educability, and as this necessarily means a greatly diminished number of myelinated cerebral axons, which are the chief agents in increasing brain growth, there must result, provided there be no compensatory increase of neuroglia or cerebrospinal fluid (which is the exception) a smaller-sized brain, which head measurement, even in its present imperfect stage, is quite capable of detecting.

A diminished number of neurons denotes a diminished degree of intelligence, except in those rare cases, where an exceptional arrangement of localised cortical neurons gives some special ability, hence the possibility of small-headed one-sided genius. Carried to a greater extreme this may result in psychopathic or anti-social reactions.

Small-headedness is, as a general rule, of more diagnostic significance than large-headedness.

Percentile tables of brain capacity are distinct aids in the diagnosis of amentia and mental subnormality. To the mental specialist, or the neurologist—and the terms should be synonymous—they frequently afford a much needed clue to the state of development of the cortical layers of the individual's brain.

Whilst head measurement and the calculation therefrom of the brain capacity will frequently fail to afford any information whatsoever, it should, nevertheless, form part of the examination of every suspected ament, and of most cases of mental disease, because in many of these there is afforded evidence that the underlying causal factor is a lack of fully developed cortical neurons. If these neurons are not there, no human agency can put them there, and the treatment must be in accordance with the physical condition.

CHAPTER XLII

THE CLINICAL DIAGNOSIS OF AMENTIA

The Diagnosis of the Secondary Amentias. The diagnosis of the secondary amentias, such as those associated with cretinism, mongolism, hydrocephalus, microcephalus, congenital deprivation of the senses, and the like, does not usually present any difficulty nor require any very special methods for its elucidation. Any reputable family practitioner can make the diagnosis with moderate accuracy.

The Diagnosis of the Primary Amentias. With the primary amentias—those due to underdevelopment of the neuroblasts and neurons, without macroscopic postmortem lesions—the case is very different. Hundreds of cases of high grade amentia pass through our consulting rooms quite unrecognised and untreated. For some minor physical ailment they receive every possible medical attention, but the grave defect of the brain passes unnoticed, undiagnosed, and untreated. “If this process” (of neglected diagnosis and treatment) “continues, the outlook for the nation is black indeed.” (MacBride.) This class of patient differs, in appearance, often but little from ordinary individuals, and yet his undeveloped brain makes him a menace to the community. He has not the ordinary standards of morality of conduct of his fellows, he has little or no idea of sexual morality, or of morality in the highest sense of the word, is often of pronounced anti-social opinions, has little or no prudence or foresight, is keener on the destruction of human institutions than their upbuilding, breeds freely, and is far too frequently allowed to survive and thrive through the misguided activities of charitable organisations who, in defiance of all natural law, encourage the survival of the unfit. To quote MacBride once more, “unless

the birth rate of these people is restricted the British nation as a virile people, is doomed."

Absolute Necessity for Early Diagnosis. It is surely, therefore, not too much to urge the absolute necessity for a change in the attitude of the medical profession to the diagnosis of the high grade ament. It seems to be a national necessity not only to attempt a diagnosis, but to make it early, and to do so for the following reasons:

Because the high grade ament seldom reacts normally to his surroundings, and may develop, consequent on his mal-developed brain and in accordance with his environment, markedly anti-social reactions, which lead him or her to crime, prostitution, and strife. He becomes a social menace.

Because he is an early prospective victim of such mental disorders as epilepsy, hysteria, dementia præcox, neuroses of various kinds, and of the psychoneuroses.

Because it is grossly unfair to normal children to be brought up alongside such aments.

Because the diagnosis and treatment of these cases is tending to drift out of the hands of the only profession competent to handle the problem—the medical profession—into the hands of lay intelligence testers, primary educationalists, and Freudian cranks.

Because, on purely medical grounds, the diagnosis of the neuronie underdevelopment, frequently throws much light on the particular physical condition for which the ament seeks medical advice, and this is particularly the case, if the ailment for which medical treatment is sought, happens to be one affecting the nervous system. Incidentally the ament is usually not a good subject for surgical operation.

Special Diagnostic Methods Required. Ordinary clinical methods of diagnosis can hardly be expected to recognize the higher grades of amentia, that is, those due to faulty development of the cortical neurons, and even though they may arouse a suspicion that all is not well with the patient mentally, they fail to detect the degree of the retardation, and hence prevent an adequate treatment. The most that such

methods can do is to establish a diagnosis of "backwardness" and the utterance of a pious, but fallacious opinion, "that the patient will grow out of it." He does not grow out of it. A patient who can be shown to be, say, three years retarded at 11 years of age, will never make up that leeway. He is an ament and he will remain one, and the treatment consists in altering his environment, that is, in placing him, if possible, in those relatively simpler surroundings for which Nature clearly intended him.

Author's Method for the Diagnosis of the Amentias. Impressed by these facts, I have for some years, devoted considerable attention to the diagnosis of the developmental amentias, and I am convinced, as a result of a long clinical experience, first, that special clinical methods are essential in the diagnosis of the amentias; second, that these methods should not replace ordinary medical methods of examining the nervous system, but should be an addition to, and extension of, the same; third, that the diagnosis should be solely in the hands of the medical profession; fourth, that psychotherapy is of no service whatsoever in the treatment; and lastly, that the methods now to be described, which have been employed by me in the diagnosis of many clinical cases of amentia for some years, have quite proved their general utility as an extension of existing methods of medical diagnosis.

As a result of a prolonged laboratory and clinical experience it is suggested that to current clinical methods there should be added, for the diagnosis of the developmental and other amentias, the following:

Estimation of the cubic capacity of the brain.

Estimation of the standing and sitting stature and the weight.

Estimation of the grip and the vital capacity.

Estimation of the Binet and Porteus reactions,

and that all the observations should be correlated with the known norms for normal children of the same age and sex, with the object of ascertaining how far, if at all, the patient departs from the normal, and the reason for the departure.

The above suggested additional examination is the very

minimum upon which any attempted examination of amentia from under-development of the cortical neurons, that is, cerebral insufficiency, should be attempted. It seeks throughout to correlate the observed clinical facts with the state of development of the cerebral cortex, and it is apparently the only practical method which makes this attempt. Further, it is based throughout on an extensive and preliminary investigation, and has been thoroughly tried out clinically. The method of enquiry is correlated throughout with the cortical investigations of Bolton, Watson, Mott, and others, fully checked and confirmed by the histological appearances of the cortex as observed and measured after death on patients whose anti-social history was known.

Second, on an examination of more than 10,000 living individuals, by Berry and Porteus, with the foregoing investigations constantly in view.

Third, on the physical examination of many thousands of children and adults by Doll, Smedley, and others.

Fourth, on the many thousands of mental examinations made in almost all parts of the world by the Binet and Porteus tests.

Lastly, on clinical experience obtained in the Children's Hospital, the Government of Victoria's Children's Welfare Department, the Juvenile Criminal Courts, and the Melbourne Hospital.

Estimation of the Patient's Cubic Capacity of Brain. The *object of the calculation* is to obtain some idea, when possible, of the relative state of development of the cortical layers of the brain, and to ascertain how far this development coincides with that revealed by the other avenues of approach. It is known that cerebrally abnormal individuals *tend* to have abnormal heads.

The *instruments* required are a pair of Flower's or other callipers, and a Grey's or Cunningham's radiometer.

The *head measurements* recorded, for the purpose of the subsequent calculation of the brain capacity are the maximum head length, the maximum head breadth, and the head height.

The *maximum head length* is measured from the most prominent point of the glabella to the most distant point in the middle line on the back of the head, known as the *occipital point*. The observer stands on the left side of the person being measured, and the fixed point of the callipers is first applied to the glabella, and held there by the fingers of the left hand, while the other point is moved over the mid-line of the back of the head (occiput). Care must be taken to observe that the fixed point has not been moved off the glabella during the measurement, and that the points of the callipers have not been deflected from the median vertical plane. The pressure of the points of the callipers on the head should be as much as can be comfortably borne by the person under examination. This diameter is recorded by means of Flower's or similar callipers.

The *maximum head breadth* is measured wherever it can be found above the plane of the ear holes. The callipers should be held in a vertical transverse plane and moved about until the maximum diameter is ascertained, the observer being careful to keep the points of the callipers exactly opposite to one another. The pressure of the points on the head should be as much as can be comfortably borne by the person under examination. This diameter, like the previous one, is recorded by means of Flower's or similar callipers.

The *head height* is measured from the mid-points of the ear holes to the highest point of the cranium measured in a vertical plane when the eyes are directed to the horizon. This diameter is recorded by means of Grey's or other radiometer.

Calculation of the Cubic Capacity of Brain. The calculation of the cubic capacity of the brain is made from the recorded diameters of the head length, breadth, and height, by means of Lee's No. 14 formula, which is as follows:

$$\text{Brain capacity} = 0.000337 \times (L-11) \times (B-11) \times (H-11) + 406.01.$$

The accuracy of this apparently complicated procedure has

been submitted to many laboratory tests, the results of which have been presented by Miss Lee to the Royal Society of London, and has also been fully checked by ourselves and others. The procedure may be regarded as accurate to within 4% in fully 90% of cases.

Supposing, *as an example*, a child aged 10 years and 6 months, that is, a child in the eleventh year of life, is found to have a maximum head length of 180mm., a head breadth of 140mm., and a head height of 120mm. From each of these diameters subtract 11mm., which is the allowance made for the thickness of the skull and the over-all soft parts, and gives 169mm., 129mm., and 109mm., respectively. Multiply these three together, which gives a product of 2376309. Multiply this by .000337, giving an answer of 800.81. To this add 406.01, which gives 1206.82 as the cubic capacity of the child's brain, or, in round numbers 1207cc.

This result is then compared with the percentile brain capacity for normal children in the eleventh year of life and of the same sex and social standing. If he be a State School child a reference to the appropriate table shows the hypothetical patient to be about the level of the 12 percentile, whereas if he were quite normal he should be at, or about, the 50 percentile. It is clear that a danger signal has thus been held out to the clinician that possibly this child is cerebrally under-developed. Further reference to the median or 50 percentiles shows that this child, though in the eleventh year of life, only has the capacity of brain of a normal child in the sixth year of life, that is, the patient is about five years retarded in head growth. As head growth is very largely determined by brain growth, as brain growth is largely influenced by medullation of cerebral axons, and as the supra-granular cortex is always the one which lags behind the others in development, it appears not improbable that some singularly useful information, in the way of a "pointer," has been obtained regarding this child. The cubic capacity would then be recorded on the chart, and the exact percentile position of the

patient indicated thereon, but *no deduction should be drawn therefrom*, until the whole of the medical, physical, and special examination is concluded.

Notwithstanding the apparently formidable character of the procedure and the calculations the actual practice is simple. Any intelligent nurse or assistant can be taught in a very few minutes to carry out the measurements, to make the necessary calculations, and record them on the diagnosis chart. It is my custom invariably to employ an assistant for this and the other tests to be made. In any case the information gained is so useful and so immeasurably superior to that of running a tape measure round the child's head as to warrant its inclusion in almost any examination where disordered mental development is suspected. For example, among 18 cases of dementia præcox between the ages of 19 and 35, in a Government Mental Hospital in Melbourne, 50% were below the 20 percentile for their age as regards cubic capacity of brain, that is, were distinctly small-headed, 25% were abnormally big-headed, with readings above the 90 percentile, and the remaining 25% came within what may be regarded as the normal range of variation, though only 2 out of the series were on the line of normality as regards head size and brain capacity. Though there are here far too few cases to warrant conclusions being drawn, the unduly large proportion of small-headedness is a fact of some significance in view of what has already been said of the association of amentia with dementia and the lack of durability of neurons.

It should be clear that head measurement, the estimation of the cubic capacity of brain, and the comparison of the result with the percentile table affords an accurate record of the patient's approximation to the normal, or the extent to which he departs therefrom. If the latter be very pronounced, the information so obtained, combined with the complete clinical, personal, and hereditary history, and the other ordinary clinical observations, will very frequently throw an interesting light on the patient's mentality, on the probable state of development of his cerebral cortex, and on the

most likely mode of reaction to his environment. It is quite well worth while to calculate the patient's brain capacity in the manner indicated.

Estimation of the Standing and Sitting Stature and the Weight. These observations have long formed an essential part of the clinical examination of patients, but it has recently been shown by Doll, confirmed by other clinicians, that these anthropometric measurements have a significance in the examination of a cerebral ament which is just as important as it is in any other medical condition, and for these reasons, supported and confirmed by one's own experience, these observations are made a routine part of the special examination of the ament.

The *standing stature* is recorded by means of a stadiometer or height standard in the metric scale. It may be incidentally mentioned that all these special observations are recorded by the metric system, for the reasons that they are the most accurate, and that all the comparative percentile tables make use of them. The subject should remove his boots, and stand on the stadiometer with the heels together, and with heels, buttocks, spine between the shoulders, and head, all in contact with the measuring rod. The chin should not be unduly raised or depressed. The examiner then brings down the sliding arm of the instrument until it rests squarely, but without excessive pressure, upon the patient's head. The result is recorded in the chart, and the percentile position of the patient, having been located from the appropriate table of standing stature percentiles, is also noted on the chart.

The manner in which the cerebral ament stands up to the stadiometer is often both suggestive and characteristic. It is expressed by the stoop in the knees, the flat feet, the poor physical tone, the round shoulders, and the sharp inclination of the chin in holding up the head. Many of the worse types face the measuring rod, or place their feet astride the base board. The normal, intelligent child on the contrary, seems at once to know what is wanted, and backs himself against the measuring rod with military erectness. Aments of all

grades—both low and high grade aments—are often below normal in standing height. There is a marked dependence of the degree of subnormality upon the degree of amentia. The high-grade aments naturally approximate more nearly to the normal, and may occasionally exceed it. All aments tend to grow at a retarded rate and to cease growth at an earlier age than the normal, and this earlier cessation of growth appears to be equally true of both body and brain. In my experience not more than 25% of aments attain the normal average of standing stature. Comparative standing stature cannot, of course, be regarded as being itself pathogenic of amentia, but, taken in conjunction with all the other tests, it often affords confirmatory evidence, because only about one-third of aments attain even to approximately normal standing height.

The *sitting stature* is recorded in exactly the same way as the standing stature, except that the subject sits erect upon the stand of the stadiometer, with the spine and head in contact with the measuring rod. If it be impossible for the subject to sit upon the stadiometer, then he should be placed upon a chair—the height of which is known—and that deducted from the height of the chair and subject—or he may sit upon the floor and be measured in that position. The record is again made in the metric scale, compared with the corresponding position on the percentile table for sitting stature, and recorded upon the chart.

Aments of all grades are often below normal in sitting stature. The high grades approximate the average. Sex differences in average sitting stature are negligible. Not more than 25% of all aments reach the normal average in sitting height. This gives a fairly high diagnostic value.

The general purpose of determining the *weight* is similar to that of determining the standing and sitting stature, namely, to furnish a comparative index of physical size or growth, as a basis for correlation with other tests or observations, and as a means of establishing any disparity, if present, between bodily physique and brain. About 43.4% of the total

body weight is produced by muscles. There is also a probable correlation between body weight and brain weight, though, as this has never been satisfactorily worked out or established, it is, as yet, impossible to establish any correlation on the living subject.

The *apparatus* required is an accurate weighing machine, preferably of the type specially devised for anthropometric work, which allows readings to be rapidly and accurately taken in the metric system with units of twentieths of a kilogram.

For very accurate measurements the weight should be taken without the clothes. Where this is impracticable, weigh with the clothes and without the boots, and deduct one-twentieth from the total weight as the weight of the clothes. The weight should be recorded in the metric system, and the results compared with the percentile tables and duly noted on the chart.

Taken alone, weight has but little value in the diagnosis of amentia, but has some value in the lower chronological years. About 40% of all aments reach the normal average of weight, especially in the higher grades of the condition.

The Physical Average. What is termed the *physical average* is the average of the three percentiles of standing stature, sitting stature, and weight. It is simply obtained by adding together the three percentiles and dividing by 3. The resultant figure is the physical average which is noted on the chart and placed in the graph in the correct position. At least 75% of all aments fail to attain the normal physical average, which would be represented by the 50 percentile. The diagnostic value of the physical average is greater for low-grade aments than for high, and it is even greater still when read in conjunction with the neuro-muscular average, to be described later.

Estimation of the Grip and Vital Capacity. The observations made under these heads are those of right grip, left grip, and vital capacity of the lungs. They are employed as part of the special examination for amentia because, though they are primarily physical or muscular tests, yet they are, to a certain extent, controlled by the nervous system. They

thus afford corroborative evidence of the diagnostic significance of the patient's brain capacity and of the physical tests. The grip tests also furnish an index of general bodily strength, of right or left handedness, and of general comparisons.

The *right* and *left grips* are estimated by means of the improved form of Smedley's dynamometer with the metric scale in kilograms. To suit the instrument to the subject's hand, the examiner adjusts the movable stirrup by trial and error, so that when the hand is loosely flexed and ready for the pull, the instrument lies squarely in the palm, facing upwards, with the outer frame set firmly against the fleshy base of the thumb and the inner edge of the stirrup touching the second phalanges of the fingers.

Allow three trials with each hand, right and left, alternately, but introduce a brief pause, say 10 seconds, between each trial, in order to avoid excessive fatigue. Induce the subject to make his best effort. Record the amount registered at each trial but, for ordinary purposes, only record on the chart the highest reading obtained for each hand.

There is considerable value in observing the reaction of the subject to this test, the awkwardness of the hands, the enormous effort without appreciable result, the facial distortion and the spasmodic bodily movements. Low-grade aments, who easily manage to wheel heavily loaded barrows, or to lift exceptionally heavy weights, frequently fail very badly at this test and do not often grip 10 kilograms. In the former case they are using the powerful muscles of the back and legs, in the latter they are asked to concentrate on a particular effort and this, the under-neuroned ament, is often quite unable to do. Strength of grip has, therefore, a high diagnostic value, inasmuch as 84% of all aments fail to reach the normal average. In view of what has been said about nerve energy this is of particular interest.

The *vital capacity*, also known as the breathing capacity, and the differential capacity, is the maximal volume of air that can be expired after taking a maximal inspiration. It is

not identical with lung capacity, because a certain amount of air, termed the *residual air*, always remains in the lungs.

The vital capacity is an important index of general physical condition and capacity, so much so indeed, that it is surprising that it is not much more frequently employed in clinical medicine as a measure of disease. It is affected by sex, age, posture, stature, occupation, amount of daily physical activity, and by disease. It may be increased by various forms of physical exercise which demand active respiration.

"When breathing quietly, a man takes in and gives out at each breath about 500cc. of air, measured dry and at 0 degrees centigrade. If measured moist and at the temperature of the body, namely, 37 degrees centigrade, the volume would be about 600cc. This amount is known as the *tidal air*. By means of a forcible inspiratory effort it is possible to take in about 1500cc. more (complemental) air. At the end of a normal expiration a forcible contraction of the expiratory muscles will drive out about 1500cc. more (supplemental) air. These three amounts together constitute the *vital capacity* of an individual. This total may be determined by means of the instrument known as the spirometer, which is merely a small gas-meter with a gauge by which the amount of air in it can be read off at once. The person to be tested fills his lungs as full as possible, and then expires to the utmost into the spirometer. The air left in the lungs after the most vigorous expiration is known as the residual air." (Starling.)

The *apparatus* required for the test is a spirometer, preferably of the wet type, fitted with detachable wooden or glass mouthpieces, with extra mouthpieces.

In recording the vital capacity see that the patient's clothing is perfectly loose about the neck and chest. Instruct him to stand upright, to take as full an inspiration as possible, and then to blow all the air he can, not too rapidly, into the spirometer. Also caution him to take care that no air escapes about the mouthpiece. Two or three trials may be allowed and the best reading recorded. As with all the other observa-

tions the result is to be compared with the correct percentile table, and the patient's percentile position duly noted.

This test offers much greater difficulty to cerebral aments than the others. The low-grade aments are unaccountably timid in the experiment and often refuse to approach the instrument. Sometimes they will yield to a little persuasion, but may become excited at any insistence. Careful instructions, supplemented by a personal demonstration, are often advisable with the ament, and it is sometimes even necessary to get the patient to make some preliminary inspirations and expirations before taking a record. The ament not infrequently blows around the mouthpiece, instead of through it, holds the mouthpiece in a helpless or stupid fashion, blows through the nose, stops the mouthpiece with the tongue, blows oftener than once, re-inspiring from the instrument. It is quite remarkable how almost unfailingly the record of the ament is below normal, and, in most cases, far below normal, in the spirometer test. Vital capacity is, therefore, highly diagnostic of amentia and of the degree of amentia. "Considering that vital capacity shows the greatest subnormality of all these measurements, that it shows the least dependence upon height and weight, and a high correlation with mental age, and that only 8% (Berry, 12%) of all aments reach the normal average, it could safely be taken as a significant reliable single index of mental incapacity." (Doll.) Professor Georges Dreyer of Oxford seems to be equally impressed with the value of the vital capacity as a diagnostic. In "The Assessment of Physical Fitness" (1920), by Dreyer and Hanson, it is stated "that if a person is found to have as much as 10% less vital capacity than is normal for his class, it is *probable* that he is suffering from some health-depressing condition, and if he is as much as 15% below the normal limit it is *practically certain* that he is abnormal in this respect."

The Neuro-Muscular Average or the Psycho-Physical Average. The neuro-muscular average—a term of more significance than that originally introduced by Doll of psychophysical average, because the former definitely suggests the

neuronic energy behind the tests—is obtained by adding together the individual percentiles of right grip, left grip, and vital capacity, and dividing the product by 3. The resultant figure is then placed upon the chart in its appropriate place. Just as the *physical average* presents some advantages over the individual physical percentiles for standing stature, sitting stature, and weight, so also is the *neuro-muscular average* most usually of greater value than the individual percentiles for right and left grip and vital capacity. Taken alone the neuro-muscular average has a high diagnostic value in the amentias, higher than any of its individual components. Only about 20% of aments reach the normal average and the correlation with mental age is quite high.

Estimation of the Mental Reactions by the Binet Test and Porteus Maze Test. These tests are usually regarded by educational Psychologists as “intelligence tests,” and they have been experimented with in many parts of the world and on many thousands of children. They have been standardised over a sufficiently large number of normal children as to justify their inclusion in a clinical examination. As thus employed, that is, in the clinical diagnosis of amentia I do not regard them as “intelligence tests” at all, but as an indication of the mode of reaction of the individual to his environment. Combined with all the other avenues of approach to the problem they undoubtedly prove their value, though it cannot be too strongly urged that diagnoses of cerebral insufficiency should not be based—as is far too frequently done—on Binet tests alone. In fact, there is no *single* test which permits, by its sole use, of such a diagnosis being made.

As regards the *Binet tests*, Professor Terman’s Leland Stanford revision of the original tests, as set forth by him in the last edition of his “The Measurement of Intelligence,” may be employed. Full instructions as to the application of these tests and their significance will be found therein.

These well-known tests comprise an age graded series of

tests of observation, vocabulary, weights and numbers, comprehension, drawing, and reasoning. Many of these Binet tests are largely tests of acquired knowledge, that is, the child who has not received a certain modicum of education will not obtain the same standard of success as the child who has, even though the former possesses a better developed cerebrum. To this extent, therefore, these tests are not so much a measure of amentia as of acquired knowledge. This notwithstanding, the ament will fail at the tests to a greater extent than will the normal child. Others of the Binet tests are purely neurological in character, those, for example, dealing with the arrangement of concealed weights are a test of the stereognostic sense. If the neurons in that part of the parietal lobe concerned in stereognostic perception are deficient in their numbers or development the child or adult will certainly fail in these tests. Broadly speaking the Binet tests apply more particularly to the incoming receptor system, especially with those extero-ceptive senses of sight and hearing upon which the literary part of an education so largely depends.

The *Porteus maze tests*, on the other hand, are largely tests of the effector mechanism. To succeed in the tests the patient must be able to control the muscular mechanism of his hand and fingers. He must also exercise a certain amount of prudence and foresight to find his way through the mazes. This the cerebrally underdeveloped child cannot do, nor can he control the use of the finer movements of his fingers, so, notwithstanding the apparent simplicity of these tests, the under-neuroned individual usually fails. These tests were worked out by Mr. S. D. Porteus on many thousands of children in Australia, and have since been confirmed and standardised by him in his more recent capacity as Director of Research at the Training School, Vineland, New Jersey, U. S. A., where full information as to these tests may be obtained.

The results obtained from the use of these two series of tests, Binet and Porteus, may be recorded on the chart

in one or other of two ways, either as an "intelligence quotient"—usually briefly referred to as the I. Q.—or in the form of percentiles, which have been worked out by Porteus for his own tests, and by the author for the Binet. As a general rule the Porteus I. Q. reads higher than the Binet for normal children, but if the combined I. Q. falls below the figure 75 or 70, especially when the other avenues of approach generally agree, it is a fairly certain indication of lack of development of cortical neurons. Those familiar with histological work on the cortex can thus be reasonably certain of their diagnosis and can predict with a considerable degree of certainty the probable reaction of the individual to his environment.

In both series of tests the intelligence quotient is obtained by dividing the patient's mental age by his chronological. The resultant figure is the I. Q. Normality is indicated by the figure 100, and the range varies from 30 or 40 for low-grade amentia—in some cases it is even zero—to about 150, the latter indicative of very high intelligence.

Regarded as a *supplement* to the ordinary clinical mode of examining a neurological case, and not as a *substitute* therefore, the above method will be found of undoubted utility. It is to be regarded as the *absolute minimum* upon which a diagnosis of cerebral underdevelopment should be founded, and if it can be supplemented by additional standardised mental and physical tests, it will be all to the good. Even in its minimum form as just set forth, the examiner seeks to obtain an accurate personal and clinical history in addition to the precise measurements and tests. This enquiry is directed along two main lines. One, is there any ascertainable or removable cause for the underdevelopment of the cerebral neurons? Two, how is the patient tending to react to his present environment?

Possible Causes of Cerebral Amentia. As regards the first point, that is, the possible causes of amentia, to the elucidation of which enquiry should be specially directed, the following are all possible causes, though it is to be distinctly

understood, that in the present state of knowledge, some of these are problematical.

Heredity is by far the most frequent and the most potent predisposing cause of nervous and mental diseases. What the patient inherits is, perhaps, not so much a disease, as an unstable or imperfectly developed nervous and cerebral system. In cerebral amentia the influence of heredity is so potent that, even if only one parent is cerebrally retarded, the children will rarely be up to standard. Where both parents are defective there is no escape.

As regards the *parents*, drunkenness of a chronic character may possibly manifest itself in the offspring in the form of idiocy, imbecility, and epilepsy, though this is by no means an established fact. The children of such debased stock are apparently born with a defective nervous organisation, and such weak inhibitory will-power as to make them fall an easy prey to social temptations. That congenital syphilis is a cause of arrested neuronie development is undoubted.

Of *pre-natal conditions*, it would appear as not improbable that improperly applied forceps, or a very prolonged or difficult labour, may do irreparable damage to the delicate neurons of the brain, possibly by causing a sub-dural hæmorrhage. Unsuccessful attempts to procure abortion, and the use of abortifacients, may also act injuriously on the developing neuron.

Of the *post-natal causes* of cerebral amentia, may be mentioned as possible factors, insufficient or improper feeding during infancy, febrile diseases during early childhood, traumatic injuries to the head, and bad hygienic conditions, particularly an insufficiency of oxygen, as well as toxæmias and bodily poisons generally. The neuron is peculiarly susceptible to deprivation of oxygen.

Reactions of the Patient to His Environment. As regards the second line of inquiry, attention should be specially directed to any reactions to the environment of an abnormal character, as well as to any average or higher abilities possessed by the patient.

Recent research into the histology and functions of the cerebral cortex, to which attention has been prominently directed in this work, has shown that the infra-granular cortex is largely concerned with animal reactions, on which the supra-granular cortex is partly inhibitory. If, therefore, the examination tends to show that the patient's brain is underdeveloped, it is a matter of practical certainty that it must be the supra-granular brain which is the more backward, and consequently the patient's reactions to the social environment will be more nearly on the animal plane of acquisition and uncontrolled displays of sex. In the human being how these reactions ultimately display themselves depends not only on the state of development of the cortical layers of the brain, but also on the environment itself. If the latter has tended to encourage anti-social reactions the patient's behaviour will also be largely anti-social. If, on the other hand, the patient's surroundings have discouraged such reactions, they will be modified accordingly. When the adult body, with its adult instincts, is coupled with the undeveloped brain and intelligence and weak inhibitory powers of a 10 year old child, the only possible outcome, except in those cases where constant guardianship is exercised by relatives and friends, is some form of delinquency. This delinquency most usually assumes one or other of two main forms, either uncontrolled sexual or homo-sexual gratification, or some form of moral delinquency, such as thieving, lying, slander. Observe how this coincides with the known functions of the two great cortical layers of the brain, and with the proved figures of crime and prostitution amongst cerebral aments.

CHAPTER XLIII

ILLUSTRATIVE CLINICAL CASES

Introduction. Having now set forth the general principles of modern neurology it only remains to illustrate their applications to clinical practice, particularly in so far as they concern those states of underdevelopment of the cerebral cortex now generically termed *amentia*. The cases which follow have been selected from a very large number seen at the Childrens' Hospital, the Childrens' Welfare Department, and the Juvenile Criminals' Court, and serve to illustrate the methods of diagnosis adopted, the correlation of the findings with the neurological condition of the cerebral cortex, as well as the social and medical prognosis. The first case will be fully set forth as a complete illustration of the conversion into actual practice of the underlying neurological principles. The remainder will be only briefly discussed.

Case 1. Low Grade Amentia Undiagnosed by the Original Consultant. The patient is a boy aged nine years and ten months, that is, he is in the tenth year of life. He is an only child whose mother died when the boy was three years old. The father is living.

The boy was breast-fed, suffered from no minor ailments, but fell out of his cot on to his head when he was seven months old. His grandmother thinks this may have affected the boy's mentality. Teething and walking occurred normally, but the child did not speak until he was five years old. Some years later the grandmother, who has had thirteen children, one of them the boy's father, began to think the boy was not quite right mentally and took him to a medical man who failed to elicit any evidence of mental abnormality. As no improve-

ment manifested itself, the grandmother was not satisfied and consulted a children's specialist who referred the child to me for a special examination and report.

No ascertainable mental history could be obtained on the father's side and the relatives knew but little of the mother's side. It was stated that the mother and her family were "highly strung" and that the mother had a brother who did not speak until he was seven years old.

The grandmother affirmed that the boy was mischievous and destructive, could not be left alone with impunity and always required watching. He has twice wandered away from school. He cannot read and can only write his own name with difficulty. He does not appear to have developed any habits of thieving or lying and there is no obtainable history of sexual proclivities. He has been at several orphanage schools, but the authorities have eventually always requested his removal from the school. He has no playmates, but has a great liking for blue glass beads and is especially fond of playing with old jam tins, which he puts in straight lines. He seems to be best with his hands, can build up match boxes to a great height and is said to get an accurate alignment of his tins and boxes. Apart from this he does not appear to have any other special aptitudes, but likes to have pictures in books explained to him, particularly of aeroplanes, and is said to have a good ear for music.

The boy's mother died from "blood poisoning" when she was three months pregnant with a second child. This is attributed to the use of abortifacients which were also extensively employed without the desired success during the first pregnancy from which this boy was born.

Whilst the foregoing clinical and personal history was being elicited—and it is obvious that the two lines of enquiry mentioned on page 539 were the objectives in view—my assistant was applying to the patient himself those standardised measurements and tests described on page 526 and entering the results on the diagnosis chart. To deal with these first.

Measurement of the boy's head gave the following results:

head length, 187 millimetres: head breadth, 140 millimetres: head height, 138 millimetres. From these figures and the use of Lee's formula (see page 528) the cubic capacity of brain is calculated out at 1378 cubic centimetres. As the boy is nine years and ten months old, he is in the tenth year of life. Reference is now made to the percentile table of cubic capacity, from which it is found that the boy falls between the 80 and 90 percentiles for State school boys, that is a direct comparison is established between this and normal boys of his own age and social standing. The 80 percentile for such normal boys is 1349cc. and the 90 percentile is 1380cc., the difference between the two being 31cc.; there is thus a spacing between the 80 and 90 percentiles of 31cc., which gives a unit difference of 3.1cc., and so the boy is seen to be, as nearly as possible, at the 89 percentile, that is, he is about 39 points more than the average of his age and sex. This figure falls within the upper range of possible abnormality and shows the boy to be macrocephalic with a head as big as that of the normal boy of sixteen years. The results of the three measurements of the head, as also of the calculation therefrom of the cubic capacity of brain, are entered on the chart. The percentile of the latter, 89, is also entered in the correct column and diagrammatically recorded in the graph as a dot.

The assistant next proceeds to take the standing stature, the sitting stature, and the weight, records each observation on the chart, turns up the appropriate percentile tables and finds that the results for this boy are as follows:

Standing stature.	1,249 millimetres.	Percentile 23.
Sitting stature.	707 millimetres.	Percentile 61.
Weight.	25 kilograms.	Percentile 27.

The average of these physical measurements, that is, the *physical average*, is obtained by adding the three percentiles together and dividing by three, which gives a quotient of 37. This last is recorded on the chart and entered on the graph.

The right grip, left grip, and vital capacity are next taken with the appropriate instruments, the results recorded and

Name. R.M. Sex. Male Birth day 9th June, 1913 Age. 9¹² years School Various Orphanage
 Address. Date of Examination April, 1923

NUMBER	MEASUREMENTS AND TESTS	RESULTS IN METRIC SYSTEM	NO OF YEARS OF RETARDATION OR ADVANCE	PERCENTILES	AVERAGE PERCENTILES	REMARKS	PERCENTILES	BRAIN CAPACITY	STANDING STATURE	SITTING STATURE	WEIGHT	RIGHT GRIP	LEFT GRIP	VITAL CAPACITY	BINET	PORTBUS	OTHERS
1	Head Length	187 mm					+100										
2	Head Breadth	140 mm					100										
3	Head Height	138 mm					90										
4	Brain Capacity	1318 cc.	+5	89	89		80										
5	Standing Stature	1249 mm	-1	23			70										
6	Sitting Stature	707 mm		61			60										
7	Weight	25 k.	-1	27			50										
8	Physical Average				37		40										
9	Right Grip	13 k.	-1	20			30										
10	Left Grip	11 k.	-2	10			20										
11	Vital Capacity	950 cc.	-3	3			10										
12	Neuro-muscular average				11		0										
13	Binet	3 ⁶ / ₁₂ Y	-6 ⁴ / ₁₂	35.6	0		0										
14	Porteus	4 ⁶ / ₁₂ Y	-5 ⁴ / ₁₂	45.7	0		0										
15	Others						-0										

Diagnosis. A low grade element of the imbecile type. The steep decline of the continuous line through the average percentiles is highly characteristic of this type of *AMENURIA*.

FIG. 131.—A diagnosis chart.

the correct percentiles obtained from the corresponding tables with the following results:

Right grip.	13 kilograms.	Percentile 20.
Left grip.	11 kilograms.	Percentile 10.
Vital capacity.	950 cubic centimetres.	Percentile 3.

The average of these three is the *neuro-muscular average*, obtained as was the physical average, with the result, 11 percentile. This last is again recorded on the graph.

Proceeding to the Binet tests, the assistant commenced by asking the boy his age, which he did not know; therefore his mental level was presumably not that of a normal five year old child and as a consequence the tests were immediately taken back to those of the four year old child. Of these he failed at the first one dealing with the comparative length of two lines, and was consequently taken right back to the tests of the normal three year old child. All these three year old tests, which are of the utmost simplicity, he passed quite correctly. The examiner then continued with the four year old tests. Proceeding with these tests in the order in which they are set forth in Terman's "The Measure of Intelligence," the patient failed to recognise the longer of the two lines (scores 0); he succeeded in the discrimination of seven out of ten geometrical forms of a simple order, which gives him a pass (scores 2 months); he succeeded in the counting of four pennies, the counting and pointing to the pennies coinciding (scores 2 months); he succeeded in copying the square (scores 2 months); he failed absolutely at the comprehension tests of "What must you do when you are sleepy?" "What ought you to do when you are cold?" "What ought you to do when you are hungry?" (scores 0); he failed absolutely at the repetition of four digits (scores 0). As the patient succeeded with some of the four year old tests, the examiner proceeded with the five year old tests, at all of which the patient failed.

As this patient succeeded with all the three year old tests, he is credited with three years *plus* two months for each of

the four year old tests in which he succeeded, which gives a Binet mental age of three years and six months. The Binet intelligence quotient for this case is, therefore, 35.6, obtained by dividing the mental age by the chronological age thus:

$$\begin{array}{rcl} 3 \frac{6}{12} \text{ years} & 42 \text{ months} & \\ \hline 9 \frac{10}{12} \text{ years} & 118 \text{ months} & \\ \hline & & = 35.6 \text{ intelligence quotient.} \end{array}$$

The examiner next proceeded to test the patient's motor or effector reactions by means of the Porteus maze tests. Commencing with the three year old test in which the patient is asked to trace with his pencil the outline of a diamond-shaped figure and to keep his tracing within the narrow confines of the printed outlines provided, the boy succeeded. He neither passed out of the confines of the space provided nor did he cut off any of the angles of the diamond. He also succeeded with the four year old test. For the five year old test he only obtained half credit, because he passed the first allowable opening and went out at the second. He failed absolutely at the six and seven year old tests. The Porteus mental age is, therefore, four years and six months, and the intelligence quotient, obtained as before, is 45.7. The combined Binet and Porteus quotient is, in this case, 40.6, and all observers are agreed that when the combined quotient falls below 70, it is a fairly reliable diagnostic of retarded cerebral and mental development.

The Binet, Porteus, and combined quotients, respectively, for this patient, 35.6, 45.7, and 40.6, are entered on the chart and recorded on the graph. On the graph, lines are then drawn between the three dots of the percentile position of this boy for cubic capacity of brain, physical average, and neuro-muscular average. Similar lines are drawn between the dots representing the mental quotients. The graph is now completed, and on every count, except the physical average, the patient is shown to be well outside the extensive range of variation allowed for normal variations from the mean, and even this physical average is seen from comparison with the percentiles to be well below that of

the average normal child of a corresponding age and social standing.

Interpretation of the Observed Facts. With all these facts before him the clinician is now enabled to pass to their interpretation, and to establish an accurate diagnosis.

As regards the observations of cubic capacity of brain, the bodily physique, and the neuro-muscular average, it is at once clear that the patient is outside the standards of normality as regards the first and the last and is below standard as regards the second. The boy is, therefore, abnormally big-headed and of inferior physique and is strikingly below normality in neuro-muscular average.

The examiner knows, or should know, that the factors affecting size of head are six in number, namely, thickness of the soft parts of the scalp, thickness of the skull, the presence of the meninges, the amount of cerebro-spinal fluid, the numbers and state of development of the cortical neurons, and the relative amount of neuroglia. The first three are negligible and for them full allowance is made in the calculations. This boy's abnormally big head is due to one or other of the last three factors, divisible into two chief groups: neurons, on which mentality depends; fluid and neuroglia on which mentality does not depend.

A survey of the patient's chart shows quite clearly that in this case the abnormally sized head is not due to neurons. Further, the neuro-muscular and mental tests prove an actual lack of neurons. Study of the ontogenetic development of the cortical neurons of the brain (see Chapter XXVII) further proves that when there is an insufficiency of development of cortical neurons, it must be the supra-granular or inhibiting cortical layer which is most at fault. The inference is, therefore, that in this case we are dealing with a boy of under-neuronic development who is incapable of exercising control over his neuronic effector responses. That this inference is correct is supported by the failure of the boy at the Porteus tests and is borne out by the personal history that he is "mischievous, destructive, and wants constant watching."

Lack of normal neuronie development is further fully supported by the gross failure at the neuro-physical tests, as well as by the low mental age obtained from the Binet-Simon tests. Further, the complete failure at the stereognostic tests of the latter system, and the complete failure to understand the meaning and use of figures show that there is a lack of neurons in the parietal association area. The boy has no planning capacity, no foresight, can count up to nine, that is, can repeat the words, but has no idea of their meaning, has a most confused sense of colour, calls a horse "pink" and yellow "white." The only things at which he has even approximately average ability are the recognition of geometrical forms and his alleged ability to distinguish musical sounds, as is proved by the tests themselves and the personal history.

With all this information before us there can be no doubt as to the diagnosis and but little as to the prognosis. The boy is a low-grade ament of the imbecile type, the condition being due to a probable general neuronie failure of development over the whole of the cortex, certainly in the supra-granular layer, induced possibly, though not certainly, by the use of strong abortifacients during pregnancy. The neuron is peculiarly susceptible to poisons.

As the boy is now ten years of age there is no hope whatsoever of his neuronie development ever making up the leeway of backwardness. He will remain an imbecile. With the onset of puberty there may be strong sexual desires aroused over which there will not be an effective controlling neuronie machinery. It is, therefore, quite possible that the patient may some day find his way either into a police court or a mental hospital.

Apart from what has already been said there are two other features of this case to which attention may be directed.

First, there is the fact that one medical man failed to elicit any evidence of mental subnormality, which proves the necessity of establishing some better method of diagnosis than a perfunctory clinical inspection of such cases.

Second, this case affords strong presumptive evidence of

the danger of locking the stable door after the steed has been stolen. Nothing will be done by society with this, and similar cases, until an offence has been perpetrated against its laws and usages, by which time it will be too late to endeavour to train along better lines the few abilities the boy does possess. Were an early and accurate diagnosis made, which should correlate the behaviour of the patient with the cortical condition of the brain, such patients would be placed in an institutional colony or village community, and society would be spared the expense and misery of their possible criminalistic depredations.

Case 2. High Grade Amentia in Lunacy. The patient is a female aged twenty-two years and six months, that is, she is in the third decade of life. She was admitted to the Receiving House of the Victorian Lunacy Department on August 22, 1921, discharged thence as relieved on October 1, 1921, at the request of her mother. Was readmitted on July 5, 1922, and has since been transferred to another mental hospital for more permanent cases of mental disorder. When first seen at the Receiving House she gave a history of freedom with boys without sexual satisfaction, has ideas of unworthiness, remorse for her actions, practises onanism, and always has an impulsive tendency to look at the region of the male genitals. In the interval between her discharge from the Receiving House and her re-admission thereto, this patient consulted a lay Psycho-analyst, who, at that time, had an extensive practice in inverse ratio to his knowledge of the functions and disorders of the brain. This individual examined the patient in a darkened room with no other person present and "cured" her. Unfortunately her sexual obsessions became very much worse after the alleged cure and, as stated, she had to seek re-admission to the Mental Hospital and is now permanently insane. Her description of the interview with the psycho-analyst, though probably quite untrue, is not such as to commend the practice of psycho-analysing cerebral aments without witnesses.

Any medical man seeing this case would probably dismiss

it as just that of a common lunatic. But what is lunacy? Is lunacy actually a disease of cortical neurons, irrespective of their numbers and development, or are mental reactions so dependent on numbers of fully developed functioning neurons as to make the reactions of the under-neuronated individual appear quite normal to those similarly constituted, and quite abnormal to those who have their full share of neurons?

There can be little or no doubt that many so-called cases of insanity are not due to diseases at all, but are simply disordered reactions to the environment from a deficiency, or destruction, or both, of fully developed functioning neurons. That is, many of the insanities are simply due to developmental failures of the cerebral cortex, in much the same way as congenital pulmonary stenosis is due to unequal division of the truncus arteriosus. Underdevelopment of the cerebral cortex necessarily leads to an altered reaction to the environment. Every living animal is provided with a nervous system which is strictly adapted to its requirements, that is, provision is made for those reactions to the animal's environment which best adapt it to the struggle for existence. When these reactions effect the purpose, they are "normal"; when they fail to effect the purpose, they are "abnormal." Man has attained his supreme position in the animal world entirely through the extraordinarily highly evolved mechanism of his brain, and it is a universal law of nature that for a high evolution there is a price to be paid. For example, the shoulder joint of man is the most highly evolved shoulder joint in the animal kingdom, and the price to be paid is frequency of dislocation. No other animal pays such a price. Similarly with man's brain. So highly evolved is it that there is a price to be paid, and that price is an occasional failure in its development, with a consequent inability to perform its proper functions of enabling man to react to his environment in a normal manner, or in the manner which society regards as normal. When sufficiently pronounced, these abnormal reactions to the environment are regarded as lunacy, and it would appear that

such abnormal reaction to the environment may be reached, in man's case, in a variety of ways.

First, it may be attained from actual diseases of brain cells in a perfectly normally neuronated individual, as when general paralysis of the insane follows syphilis. Here, as the neurons become slowly destroyed there is a gradually increasing abnormal reaction to the environment, and the condition, when sufficiently obvious, is called insanity.

Second, it may be reached from an arrested development of cortical cells. Differences in the degree of the arrested development range from extreme cases, such as microcephalic idiocy, through all the grades of cerebral amentia, up to sub-normality. As Mott says, "there is definite clinico-anatomical evidence of the inseparability of body and mind. Thus mental deficiency is associated with and proportional to the arrest of development of the supra-granular layer of pyramidal cells of the cerebral cortex." All these patients show in their behaviour a more or less abnormal reaction to the environment. The greater the deficiency in cortical cells, the more pronounced are the abnormal reactions. Are all such conditions to be classified as insanity? The present tendency appears to be to call only those insane whose reactions to the environment depart very markedly from the normal, and it is clearly a matter of the greatest difficulty to separate here the sane from the insane.

Third, it may be reached from a natural destruction of cortical cells such as occurs in every human individual who lives long enough, and is, indeed, a perfectly natural attendant on senility, and gives, of course, abnormal reactions to the environment in an individual who previously has reacted perfectly normally. When this occurs in elderly persons it is regarded as a normal process. When it occurs in younger individuals it is called insanity, and classified as dementia præcox.

Fourth, it may be reached from "ill-health" of the cortical neurons in a previously normally developed individual with his full share of neurons, who has previously reacted quite

normally to his environment. Under these conditions of 'ill-health' of the cortical neurons the reactions to the environment become so profoundly altered, sometimes temporarily, sometimes permanently, as to cause considerable difficulty in saying when such persons are to be regarded as insane and when not. Further, these conditions of "ill-health" of the cortical neurons may occur in any individual, irrespective of the numbers of his neurons, and so become grafted on to amentia or genius. The reactions to the environment become thus still further modified and lead to still greater difficulty in the classification of the condition.

Of the effects of this "ill-health" of the cortical neurons, however produced, there are numerous examples in medicine. To mention but a few, in all of which, however, the reactions to the environment are so profoundly altered as to make it difficult to know when the narrow line of demarcation between sanity and insanity is crossed, there are, delirium in acute fever, acute mania after an anæsthetic, and delirium tremens.

The patient under discussion, when first seen, certainly displayed pronounced abnormalities to her sexual environment, but whether these were sufficiently marked as to warrant certification is another question. The special examination we made of her gave the following results:

Cubic capacity of brain	1279cc.	26 percentile
Physical average		43 percentile
Neuro-physical average		27 percentile
Binet-Simon age.	13 years	82 I. Q.
Porteus age	12 years	78 I. Q.

In this case the results appear at first sight rather inconclusive. On every count the girl appears within the allowed range of variation. Closer scrutiny shows, however, that all data are distinctly subnormal, and these facts, combined with the clinical history, certainly suggest that the patient was under-neuroned from the start, and is now suffering, in addition, from a lack of durability or even local destruction of the remaining brain cells she possesses. Sir Frederick Mott has stated that "great care must be taken (in the use of psychotherapy in medicine) not to put into the mind ideas of sexual

perversion." It is not improbable that the visit to the lay psycho-analyst provided the very stress which caused an under-neuroned brain to break down and the patient is now a certified lunatic.

Cases 3 and 4. Illustrative of the Dangers of Establishing a Diagnosis on One Test Alone. The patients are twin sisters, aged fifteen years and four months, that is, are in the sixteenth year of life. They are both from the same institution and as the authorities could not understand the differences presented by the sisters, they asked me to examine them, with the results set forth, as follows:

	I. L.	M. L.
Cubic capacity of brain	86 percentile	61 percentile
Physical average	12 percentile	4 percentile
Neuro-physical average	74 percentile	13 percentile
Binet-Simon quotient.	71.	50.
Porteus quotient	100.	41.

Had these girls been examined by the Binet test alone, it is not improbable that both would have been returned by the lay Psychologist as "feeble-minded" and a grave injustice would have been done in the case of I. L. Both sisters are of small bodily physique and of the big-headed type. I. L. is a not unintelligent child whose comparative failure at the Binet tests is due to lack of educational opportunities. M. L. on the other hand is a high-grade ament. The authorities of the Institution were advised to give I. L. extended educational facilities and this advice has been followed with the happiest results. As regards the sister, a benevolent control seemed to be indicated. She has, therefore, been retained in the Institution and under the relatively simple environment in which she there finds herself, is making herself both useful and happy. Had she been allowed to go out into the world there is little doubt what would have been her fate.

It is, unfortunately, only too common amongst educational Psychologists, to establish a diagnosis of "feeble-mindedness" on a Binet intelligence quotient alone, without any medical or physical examination whatsoever, and the practice is both dangerous and inexpedient. As Porteus remarks: "A

Binet intelligence quotient of 70 or less may be regarded as the first presumptive evidence of feeble-mindedness, but by no means as a final diagnostic proof. Though this is almost universally conceded, yet we find study after study, presumably directed towards the problem of what does and does not constitute feeble-mindedness, quoting a Stanford-Binet intelligence quotient as if it were quite adequate to determine the status of the subjects of the investigation. The practice appears to be on all hands to repudiate such a method of diagnosis and just as generally to adopt it."

Whatever the practice may be among laymen, and it is to be feared that Porteus's remarks are only too true, the procedure is quite inadmissible in medical practice. There is no single test which is capable of detecting cerebral abnormality, and the cases of these twin sisters emphasise the point.

Case 5. A Case of Microcephalic Amentia with Moral Delinquency. The patient is a girl, aged eleven years and eight months, that is, she is in the twelfth year of life. She was taken to a children's specialist with the following story:

The child was apparently quite normal until about the age of six years, when she developed a habit of stealing anything she could lay her hands on, whether of value or not. It was also noticed that she was not truthful. These thieving and lying propensities gradually became more pronounced and are now the source of much trouble with the neighbours, so much so indeed that the mother has been compelled to leave one residence after another, on account of the child's propensities. The child has been in six convent schools and has always been reported as incorrigible and has had to be taken away. In other respects the child is normal, is clean in her habits, very affectionate and good-hearted and quite penitent for the moment and when found out in her delinquencies, but "does it again."

On directing enquiry to any possible causes of cerebral underdevelopment, it was found that the child was the offspring of a first pregnancy when the mother was about sixteen or seventeen years of age, the child being born in wedlock.

The labour was difficult and a forceps delivery. The mother herself thinks the labour may have affected the child's head. The infant was fed from birth on condensed milk, no cow's milk being available. There is no history of any delayed acquisition of speech, nor of any abnormalities in the processes of dentition or walking.

The child suffered from an attack of diphtheria at the age of seven years and six months, developed post-diphtheritic paralysis of the legs with an affection of speech. Prior to this illness the mother is of opinion that the child was mischievous only, but that afterwards habits of theft and lying developed.

Directing the next line of enquiry to the hereditary history, there was stated to be a "distinct mental weakness" on the father's side. He was alleged to have been a "waster," "light-fingered" and would steal spoons and other things from restaurants. The son of one of his sisters is "mentally defective." Another nephew is deaf and dumb and is in an institution. His father was an alcoholic and "would go mad when he was drunk." The husband himself, though fairly reasonable when sober, was violent and unreliable when drunk and had such a small head that he had to have his hats specially made. The mother now recognises that her marriage was a mistake and has left her husband.

As regards the child the mother complains of the propensities already set forth. In one city the police were after the child four times for theft. On one occasion she stole a bicycle, left it at a street corner and eventually denied all knowledge of the transaction. There is, as yet, no obtainable history of any sex proclivities, but she gets very angry if her younger brother comes into the room when she is dressing. The patient is good at needlework and housework, can recite and sing a little, and has been taught step-dancing. She is of a kind-hearted disposition, affectionate and loving, clean in her person, but an incorrigible liar and thief.

From her diagnosis chart the child is found to be very small-headed and of poor physique. She has the average sized

head of a child of about five years, that is, there is a seven years retardation, which is highly significant of developmental amentia. Her bodily physique is that of a normal child of nine years, that is, two years retardation. Her neuro-muscular average is also below normal, though not so much so as the other observations. The Binet age is eight years, or three years and eight months retardation, with an intelligence quotient of 68. The Porteus tests show a slight advance over the chronological age, with a mental age of twelve years and six months and a quotient of 107. An actual and serious retardation is thus shown on every count except the effector mechanism.

From all this it may reasonably be inferred that we are dealing with an ament of the small-headed type, in whom the animal instincts from an infra-granular cortex are quite well developed, but over which there is an insufficient inhibition from an underdeveloped supra-granular cortex, as is shown by the clinical history supported by the small head and corroborated by the Binet tests. These last bring out the facts that the child has little or no moral sense, has not the memory of a normal nine year old child, has a limited speech vocabulary and has little stereognostic sense.

It will be remembered that the functions of the infra-granular cortex are, broadly speaking, those of acquisition, that is, of acquisition of those things essential to life and the species, namely, food and sex. Man is the only animal with a supra-granular cortex sufficiently well developed to enable him to inhibit these reactions. Consequent on the greatly extended range of the infra-granular cortex in man the animal property of acquisition assumes many diverse forms, either taking the actual thing or its human representative—money. With an insufficiently developed controlling supra-granular cortex the individual, given the environment, tends to react on this animal basis of acquisition, hence it may be very generally stated that individuals of this character are apt to display anti-social reactions against either human property or the human person or both. This child is, as yet, too young

to make any prognosis possible as to future anti-social reactions of sex, but as regards anti-social reactions against property they are only too well established, and the special examination employed by the Author brings out the reason why—namely, an insufficiently developed supra-granular cortex of control. As this is clearly underdeveloped, it is useless to attempt moral suasion or to punish the child for her lapses and it is equally useless to expect any therapeutic treatment to put brain cells where Nature has denied them. The child requires constant guardianship by either the relatives or the State. If the State refuses this duty, then, from this child, there can only be expected anti-social reactions against its established laws and usages, which are those laid down by normal people for normal people. Present-day folly consists in still expecting the cerebrally abnormal, of whom there are more outside institutions than in them, to react on normal planes of control and inhibition, and in supposing that the phenomena of mind and its many aberrations can be studied and discussed without any knowledge of Nature's greatest masterpiece—the human brain. The Nervous System pervades every phenomenon of life, both in health and disease, and its study will repay the student of Sociology, Medicine, and Jurisprudence.

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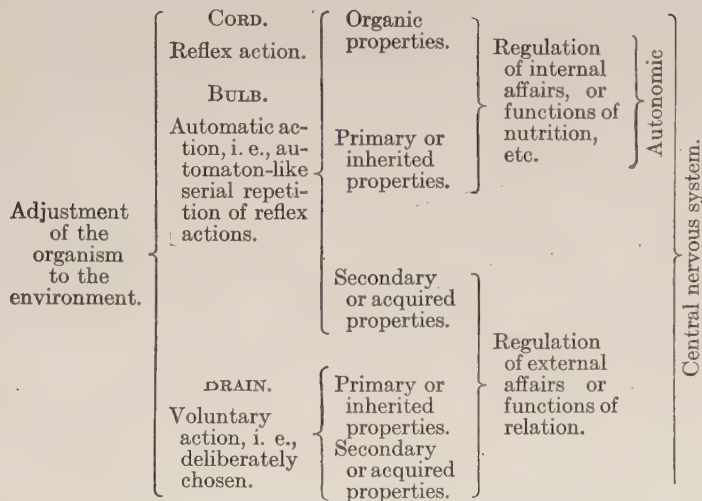
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APPENDIX

Summary of the Phenomena of the Nervous System. The phenomena of the nervous system are those of life itself. Subject to slight modification, the summary of these phenomena, as given by Professor A. D. Waller in 1893, is still good and is as follows:



Reflex Action. A reflex act may be defined as the immediate effector or motor response to centripetal receptor excitation. It is unchosen and inevitable, and the nature of the effector response to the receptor stimulus is always the same. Irritation of the conjunctiva, for example, causes a reflex effector winking of the eyelids. Sneezing and coughing, although more complicated in their neuronie machinery, are still reflex acts. Peristaltic action of the intestine is entirely reflex in its mechanism.

If the *peripheral receptor stimulus be too weak*, the reflex act may not take place at all; the receptor neuron having been insufficiently stimulated, has not discharged sufficient energy

to excite the effector neuron and consequently there is no effector response.

If, on the other hand, the *peripheral receptor stimulus* be *too powerful*, the resultant effector response will take place in spite of any voluntary effort to control or inhibit it.

Reflex action may, therefore, be, and often is, performed unconsciously and never becomes known; or it may be unconsciously performed and subsequently become known, or it may be perceived during its performance. However performed, reflex neuronie actions are essential to the maintenance and preservation of life, and most of the reactions of viscera, glands, etc., are of this type, and are operated through simply constructed reflex neuronie arcs, with the cell stations of the preganglionic effector limbs of the arcs, situated, for the most part, within the spinal cord. But the term "reflex action" also includes many other highly complex bodily activities, such as modification of the heart's beat, contraction and relaxation of blood vessels, with the resulting blushings, pallors, faintings, palpitations, and the like, all of which occur independent of the will. All these, and similar reflex bodily activities, are brought about by the discharge of nerve energy over effector neurons, in response to stimuli transmitted centrally by the receptor neurons of the reflex neuronie arcs concerned. Further, the effector response to the receptor stimulus may obviously be of two kinds, diminution of action or augmentation of action, according as to whether the parasympathetic or vertebral sympathetic portion of the autonomic nervous system momentarily predominates.

Automatic Action. Automatic action, although it is somewhat intermediate between reflex and voluntary action, is, in essence, reflex action serially repeated. It is, therefore, a series of immediate motor reactions, that is, repeated or rhythmic motor or effector responses to repeated or continuous receptor excitations. Automatic action is usually carried on unconsciously, but it may, upon occasion, be governed by the will, and may thus be accelerated or restrained by voluntary action. The movements of respiration, sucking, and walking, are the most typical among many automatic actions, and each

of them is a more or less prolonged and rhythmic series of effector responses to prolonged or repeated excitations. The largely automatic act of walking is, for example, largely comprised of a prolonged series of serially repeated effector movements in response to a series of serially repeated extero- and proprioceptive excitations caused by contact with the ground, and the state of muscular tension, and the act may be performed consciously or unconsciously. Skilled movements, such as writing, drawing, or speaking, are on the borderland between automatic and voluntary action. They begin as slowly acquired voluntary movements, and later become largely automatic, that is, the neuronics concerned become trained and eventually "tracked" with constant use. This is the physiological Law of Facilitation, which is really the Law of Habit. "When a nerve impulse has passed once through a certain series of neurons to the exclusion of others it will tend, other things being equal, to take the same course on a future occasion, and each time that it traverses this path the resistances in the path will be smaller. Education is the laying down of nerve channels in the central nervous system, while still plastic, by this process of facilitation along fit paths, combined with inhibition (by pain) in the other unfit paths. Memory itself has the process of facilitation as its neural basis" (Starling).

Automatic action is thus an action which *appears*, at first sight, to be voluntary, though often unconsciously performed, and to be without discoverable cause. As a matter of fact every automatic action, whatever its nature, is really the result of a discoverable receptor stimulus, and thus only differs from a reflex action in the habitual or serial repetition of effector or motor responses to serial or habitual receptor stimuli.

Waller divides automatic action into two groups, one, the primary or inherited, such as respiration, sucking, etc., and two, the secondary or acquired, such as writing and speech. The largely automatic nature of ordinary speech has already been referred to in chapter 32. Walking as an automatic action occupies an intermediate position. It is *primary* in

so far as the disposition to walk is inherited, that is to say, the neuronie machinery is present from birth. It is *secondary* in so far as a child must learn to walk by practice, that is, its neurons must be educated to the task.

Voluntary Action. Reflex, automatic, and voluntary actions overlap, in the human body, to such an extent as to make it clear that such words can only be arbitrarily defined. The neuronie arc is, however, the instrument of all three, but becomes more complicated, particularly in the numbers of neurons interposed between the receptor and effector limbs of the arcs, as the scale is ascended from purely reflex, through automatic, to voluntary. All nerve phenomena are, therefore, built up on a basis of reflex actions and neuronie arcs. Everyone believes, however, that his voluntary actions are spontaneous and freely chosen in spite of exciting or receptor impulses. The belief is quite untrue and is based upon a fundamental ignorance of the receptor impulses concerned. Voluntary action is really a highly disguised and complicated form of reflex action, with its causal receptor excitations more or less concealed and sometimes difficult to discover. Some of these voluntary actions have their causes more or less deeply buried in the past history of the individual, or of the ancestors, but all of them result from previously incoming receptor stimuli, many of which become stored up in the numerous internuncial neurons of the cerebral cortex and so give rise to effector responses which may be long subsequent to the receipt of the stimuli to which they are the response, that is to say, the effector response is delayed. The only really essential difference between a purely reflex action and a voluntary one is, therefore, that the former gives an immediate unchangeable, and "fatal" response to the stimulus, whereas the latter provides for a delayed, variable, and "free" response, and is thus the structural basis of those mental phenomena termed "mind."

The structural unit of the *reflex action* is a simple neuronie arc with few internuncial neurons. The neuronie pathway is deeply "canalised"; the alternative reactions are few, and the particular stimulus is easily predicted.

The *voluntary action*, on the other hand, necessitates a very complex series of neuronic arcs with very numerous internuncial neurons. The physiological pathway is not performed in its entirety, on account of the numerous alternative pathways provided by the multiplicity of interposed cortical internuncial neurons. Further, these interposed cortical neurons possess the property of storing up receptor impulses which reach them and so may delay or arrest the immediate performance of an effector response to the stimuli. Delayed and alternative reactions are thus numerous, and the particular reaction to a stimulus cannot, therefore, be predicted with the same certainty as a spinal cord reflex action over a simple neuronic arc. The phenomena of mind are thus the result of an accumulation of stored up stimuli, and for its highest manifestations there are necessary a sufficiency of cerebral neurons, and a multiplicity of receptor stimuli.

Waller states that "a single voluntary contraction, a shorter or longer series of voluntary contractions, the lifelong pursuit of a policy, alike imply certain elements." If these elements of Waller be placed alongside their structural units it will be seen how important is the study of the latter.

FUNCTION	STRUCTURE
1. The consciousness of a desire, <i>i.e.</i> , sensation.	Receptor stimuli, receptor organs, and receptor neurons.
2. Comparison and deliberation of cerebral ideas, <i>i.e.</i> , judgment.	Neopallial internuncial cortical neurons.
3. Executive action, <i>i.e.</i> , voluntary motion.	Effector neurons and organs.

Necessity of Studying the Nervous System as a Whole. The patient and prolonged investigations of Golgi, Cajal, Bolton, Mott, Flechsig, Campbell, Brodmann, Bevan Lewis and very many others in all branches of Neurology have accumulated an enormous amount of histological and functional facts relative to the nervous system. To the vast majority of the medical and lay publics these facts appear, unhappily, to be quite unknown, and hence the almost incredible amount of nonsense pervading many of the current theories of mind. Even in Medicine the tendency is to divide up the nervous system into separate entities and specialties, such

as the study of diseases of the Nervous System, Psychiatry, and Psychology, and to regard each one as having little or no connection with the others. The fact of the matter is, of course, that the nervous system is a most delicately balanced whole, and no one part of that system can be studied successfully apart from any other.

As currently understood *Psychology* endeavours to study the phenomena of mind, that is, the functions of the healthy and normal brain, and does so, only too frequently, without any reference to the structure, development, diseases, or functions of that brain. *Psychiatry*, on the other hand, attempts the study of mental disorders, that is of the unhealthy, abnormal brain, but usually omits all reference to embryological lack of development. The study of medical *diseases of the nervous system* is usually restricted to the diagnosis and treatment of lesions of the conducting systems of neurons, and only too frequently ignores the mental effects which must be induced by these lesions. The current clinical subdivisions of the nervous system into separate specialties is, therefore, empirical and somewhat misleading, and only too frequently breeds and perpetuates error. It would surely be better if such specialties were replaced by one single entity—Neurology—and Neurology should deal with the development, structure, functions, and diseases of the whole of the nervous system, thus:

STRUCTURE.		FUNCTIONS — NORMAL AND ABNORMAL	
NEUROLOGY.	{ Receptor neurons	{ Normal . . .	Nervous disease.
	{ Cerebral internuncial neurons.	{ Abnormal. . .	Psychiatry.
	{ Effector neurons.		Nervous diseases.

Clinical Examples. As illustrative clinical examples the following may suffice.

A. *Disturbances in receptor neurons of arcs.* Tabes dorsalis or locomotor ataxy is a degeneration of the primary series of receptor neurons over which proprioceptive impulses, and probably some exteroceptive impulses, are conveyed centrally, the destruction being produced by the toxin of the spirochaete. If the disease occur in *middle age*, the mental phenomena

which may follow the loss of certain important receptor stimuli, will be slight, because the cerebral cortex has already been educated, and the patient has learnt to employ other "senses" to supplement those he is losing. If, on the other hand, the disease occur in *early youth*, as in juvenile tabes (disease of the nervous system), then mental disorder (Psychiatry) may quickly supervene, because the correct receptor stimuli are cut off before the cerebral cortex has been correctly educated, and further the cortical neurons are not sufficiently stabilized, and are thus, in their turn, attacked and destroyed by the disease. Juvenile tabes does not, therefore, involve two specialties, but one.

Syringomyelia is another disease which, in its earlier stages, is characterized by an interference with the receptor conducting neurons of sensibility, heat, cold, and pain. Later, on account of the loss of spinal cord substance, and pressure from the proliferating neuroglia, other conducting neurons, such as the final common effectors (lower motor neurons), may become involved, and hence the slow wasting of muscles.

B. *Cerebral internuncial neurons*. Normal behaviour, that is, those reactions to the environment, currently regarded as normal by normal people, depends primarily on a sufficiency of stabilized cortical neurons, particularly in the pyramidal-celled cortical layers, and secondarily on the state of health of those neurons. An insufficiency of cortical neurons, often developmental in origin, produces those slightly disordered reactions to the environment characteristic of the amentias. When this insufficiency is still more pronounced, the disordered reactions to the environment become so dangerous, either to the individual or the community, that the Law demands certification under its Lunacy Acts. The same general results are obtained in perfectly normal individuals from a destruction of cortical neurons from both diseases and poisons. General paralysis of the insane is an example of the former—destruction of cortical neurons from the virus of syphilis, and common drunkenness of the latter. In both there are disordered reactions to the environment, permanent or temporary according to the cause.

The study of these reactions to the environment, that is, of the phenomena of mind, is, therefore, inseparable from Neurology as a whole, and is not, as so many non-medically trained Psychologists appear to believe, a separate entity. In so far as Psychology seeks to study the behaviour of the individual and the species it becomes that special branch of Neurology which is more justly termed *Brain Physiology*. Brain physiology cannot be successfully studied apart from other portions of the nervous system, because those other parts are perpetually pouring in stimuli to the cerebral cortex and are as perpetually altering its construction and the reactions of the individual to his environment. The human mind in its individualistic character is thus perpetually altering.

Psychiatry, on the other hand, is a purely medical study of those aberrations of the phenomena of the human mind, which result from an original insufficiency of cerebral internuncial neurons (amentia); a destruction of such neurons, which, when premature, probably gives rise to the mental aberrations of dementia præcox, and when physiological, to the dementia of senility; a destruction of cortical neurons from disease in an otherwise normally constructed neuronic brain, as in the mental aberrations of the General Paralytic, and though not usually regarded as a branch of Psychiatry, the aphasias, because the essential basis of the aphasias is again a greater or less degree of destruction of cortical internuncial neurons. It is, therefore, clear that Psychiatry can no more be regarded as a specialty apart from the nervous system than can Psychology, because the phenomena presented concern the nervous system as a whole.

C. *Disturbances in effector neurons of arcs.* These are the best known of all aberrant nerve phenomena, because when the effector neurons are destroyed the signs of paralysis are obvious even to the most ignorant. Lesions of the clinician's "upper and lower motor neurons" are well known, but only too frequently even the clinician forgets the numerous other neuronic pathways which go to control voluntary muscular action, and seldom works out the mental and other results

to the patient, of the failure of what may be termed the "neuronic circulatory arc," that is, the failure of the receptor impulses to pass, as they should do, through to the effector neurons. These stimuli become, therefore, arrested in their circuit, and so may produce mental phenomena. It is unnecessary to furnish examples of lesions of the effector sides of neuronic arcs as many examples will occur to any medical reader.

Conclusion. There can be no question that the study of the phenomena of life, whether in health or disease, is immensely advanced if the attempt be constantly made to refer these phenomena to their respective sides of the neuronic arcs, receptor, internuncial, effector. It may be readily admitted that as yet, there is an insufficient knowledge of all the neuronic arcs concerned. The average medical man, because he himself may be unfamiliar with any of these arcs, too readily assumes that none are known, and hence never makes the attempt, and consequently may fail to cure many diseases which he might cure. The whole study of disease, as well as its successful treatment, becomes immensely more interesting and certainly more amenable to treatment, if the symptoms be constantly referred to the sides of the neuronic arcs affected and concerned. This is particularly applicable to visceral disease. Pyloric stenosis and intussusception are both conditions induced by disturbances of the autonomic arcs concerned.

Lastly, all the phenomena presented by the functioning of the nervous system, normal and abnormal, and whether currently regarded as belonging to Psychology, Psychiatry, or the medical study of diseases of the conducting neurons, fall into four great groups,—absence, diminution, perversion, or exaggeration, of the functions of the three great structural divisions of the central nervous system, receptor, internuncial, and effector neurons.

Sensations or receptor neurons.	}	Absence.
		Diminution.
Thought. Cortical internuncial neurons.	}	Perversion.
Motion or effector neurons.		Exaggeration.

MALES

TABLE I.—THE BERRY-PORTEUS PERCENTILES OF BRAIN CAPACITY EXPRESSED IN CUBIC CENTIMETRES.

PERCENTILES	7TH	8TH	9TH	10TH	11TH	12TH	13TH	14TH	15TH	16TH	17TH	18TH	19TH	ADULT	
0	1074	1093	1049 1160	1092 1124	1104 1194	1110 1158	1133 1166	1081 1162	1135	1127	1225	1145	1182	1272	State School Boys Public School Boys
10	1151	1173	1183 1206	1196 1222	1202 1239	1202 1224	1214 1263	1231 1255	1265	1307	1320	1350	1381	1370	State School Boys Public School Boys
20	1181	1196	1213 1227	1223 1256	1233 1265	1233 1255	1250 1293	1267 1292	1308	1336	1356	1380	1403	1411	State School Boys Public School Boys
30	1196	1220	1237 1257	1241 1269	1251 1279	1258 1278	1273 1312	1288 1318	1330	1360	1386	1403	1427	1442	State School Boys Public School Boys
40	1217	1238	1249 1264	1259 1295	1273 1293	1278 1295	1293 1323	1308 1338	1352	1382	1401	1423	1448	1463	State School Boys Public School Boys
50	1232	1253	1265 1282	1277 1304	1289 1315	1298 1323	1310 1340	1330 1357	1377	1404	1415	1448	1466	1481	State School Boys Public School Boys
60	1243	1269	1279 1297	1294 1316	1306 1333	1315 1349	1329 1362	1348 1373	1398	1425	1434	1467	1483	1509	State School Boys Public School Boys
70	1265	1286	1299 1333	1312 1326	1331 1354	1336 1360	1349 1382	1368 1391	1426	1452	1459	1486	1495	1582	State School Boys Public School Boys
80	1289	1313	1324 1344	1349 1345	1354 1378	1364 1387	1379 1417	1397 1412	1460	1477	1483	1520	1520	1553	State School Boys Public School Boys
90	1324	1347	1354 1380	1380 1372	1384 1399	1397 1428	1413 1447	1439 1455	1487	1507	1522	1551	1551	1589	State School Boys Public School Boys
100	1432	1497	1504 1480	1517 1504	1604 1489	1587 1593	1540 1539	1630 1690	1608	1593	1655	1653	1637	1669	State School Boys Public School Boys

For the method of using this and the following percentile tables, see Chapter XLIII.
The years of life are shown, in all tables, in the top horizontal line.

MALES

TABLE II.—THE SMEDLEY PERCENTILES OF STANDING STATURE EXPRESSED IN MILLIMETRES.

PER- CENTILES	6TH	7TH	8TH	9TH	10TH	11TH	12TH	13TH	14TH	15TH	16TH	17TH	18TH	19TH	ADULT
0	969	988	1036	1097	1072	1166	1131	1252	1311	1305	1323	1420	1376	1610	1577
10	1030	1067	1125	1161	1214	1259	1291	1330	1400	1435	1493	1550	1604	1659	1636
20	1045	1093	1146	1185	1243	1287	1324	1364	1428	1468	1538	1593	1642	1677	1662
30	1055	1112	1163	1201	1261	1304	1342	1381	1446	1492	1562	1618	1662	1695	1669
40	1065	1123	1172	1216	1274	1318	1357	1403	1462	1523	1589	1650	1678	1720	1700
50	1079	1135	1190	1230	1285	1332	1378	1421	1484	1550	1616	1672	1684	1742	1713
60	1090	1148	1200	1245	1299	1345	1389	1437	1505	1569	1629	1687	1711	1748	1720
70	1100	1159	1212	1262	1316	1362	1403	1457	1528	1592	1652	1706	1722	1764	1742
80	1112	1179	1225	1278	1336	1380	1425	1479	1557	1614	1682	1732	1737	1784	1775
90	1124	1200	1248	1320	1369	1415	1452	1507	1599	1666	1715	1750	1776	1814	1792
100	1183	1289	1360	1382	1478	1479	1639	1613	1730	1763	1846	1853	1828	1839	1847

MALES

TABLE III.—THE SMEDLEY PERCENTILES OF SITTING STATURE EXPRESSED IN MILLIMETRES.

PER-CENTILES	6TH	7TH	8TH	9TH	10TH	11TH	12TH	13TH	14TH	15TH	16TH	17TH	18TH	19TH	ADULT
0	550	568	587	607	585	555	632	642	696	700	647	724	737	830	841
10	588	603	626	642	664	679	692	710	734	750	775	810	838	865	878
20	595	616	638	653	674	693	706	722	747	765	796	835	866	886	888
30	601	623	644	662	683	700	714	732	756	778	810	849	876	902	892
40	606	630	652	670	690	707	723	741	763	790	821	861	887	914	898
50	612	635	658	676	697	714	730	749	770	802	837	876	897	926	902
60	617	641	664	683	706	720	739	757	782	813	850	886	910	929	910
70	625	648	670	690	713	726	748	764	794	826	865	895	916	932	924
80	630	657	679	700	722	735	755	773	808	845	881	907	925	937	936
90	643	688	689	710	733	746	767	786	831	868	900	923	944	955	940
100	697	707	732	756	786	780	819	837	944	950	958	957	963	997	961

MALES

TABLE IV.—THE SMEDLEY PERCENTILES OF BODILY WEIGHT EXPRESSED IN KILOGRAMMES

PER- CEN- TILES	6TH	7TH	8TH	9TH	10TH	11TH	12TH	13TH	14TH	15TH	16TH	17TH	18TH	19TH	ADULT
0	13.725	15.875	17.000	17.900	20.000	19.500	18.850	25.200	28.150	25.900	30.150	34.550	34.225	45.575	53.700
10	16.675	18.275	19.850	21.450	23.650	25.375	27.675	29.700	33.150	35.200	39.650	45.675	49.200	53.800	56.050
20	17.075	19.050	20.650	22.350	24.800	26.850	28.855	31.300	35.100	37.900	43.125	48.600	53.400	56.440	58.740
30	17.600	19.575	21.200	23.175	25.575	27.750	30.075	33.000	36.450	40.150	46.375	50.725	55.000	60.100	62.660
40	17.950	20.050	21.900	23.900	26.500	28.525	31.200	33.525	37.700	42.050	48.350	53.350	57.200	62.360	65.150
50	18.475	20.475	22.450	24.300	27.200	29.450	32.162	35.200	38.800	44.125	50.100	55.500	58.975	63.825	66.950
60	18.750	21.100	23.000	25.300	28.125	30.200	33.285	36.350	40.925	45.900	52.200	57.350	61.350	64.875	68.040
70	19.350	21.950	23.800	26.025	29.025	31.400	34.300	37.700	42.850	47.975	54.425	58.700	64.100	65.600	69.860
80	20.100	22.725	24.500	27.100	30.000	35.525	35.650	40.800	44.800	51.150	57.150	61.770	66.150	67.340	70.040
90	21.550	23.525	25.600	28.800	31.575	34.500	37.865	42.350	48.400	55.300	61.673	66.090	70.975	71.360	74.600
100	26.650	29.600	32.025	62.200	38.600	50.400	52.400	64.375	72.700	68.325	97.925	105.625	81.400	83.800	92.100

MALES

TABLE V.—THE SMEDLEY PERCENTILES OF RIGHT AND LEFT GRIP
EXPRESSED IN KILOGRAMMES.

RIGHT GRIP															
<i>Per- cen- tiles</i>	<i>6th</i>	<i>7th</i>	<i>8th</i>	<i>9th</i>	<i>10th</i>	<i>11th</i>	<i>12th</i>	<i>13th</i>	<i>14th</i>	<i>15th</i>	<i>16th</i>	<i>17th</i>	<i>18th</i>	<i>19th</i>	<i>Adult</i>
0	4	5	5	7	8	10	11	10	13	15	14	17	20	36	37
10	5	8	9	10	11.5	13	15	17	19	21	26	30	35.5	41	46
20	6.5	9	10	11	13	14.5	16	18	21	22.5	28	34	39	44	49
30	7	10	11	12	14	16	17	20	22	24	30	36	41	46	50
40	8	10	11.5	13	15	16.5	18	21	23	26	32	39	43.5	48	51
50	9	10.5	12	13.5	16	17	19	22	25	28	35	41	45.5	49.5	52
60	9.25	11	12.5	14.5	16.5	18	20	23	26	30	38	44	49	51.5	54
70	10	11.5	13	15	17	19	21	24	28	32	40	45	51.5	54	56
80	10	12	14	16.5	18	20	23	26	30	35	43	48	53	58	60
90	11	13.5	15	18	20	22	25	28	33	40	47	50	58	62	61
100	16	16.5	20	24	30	32	31	37	62	56	63	85	72	71	69

LEFT GRIP															
<i>Per- cen- tiles</i>	<i>6th</i>	<i>7th</i>	<i>8th</i>	<i>9th</i>	<i>10th</i>	<i>11th</i>	<i>12th</i>	<i>13th</i>	<i>14th</i>	<i>15th</i>	<i>16th</i>	<i>17th</i>	<i>18th</i>	<i>19th</i>	<i>Adult</i>
0	3	4	5	7	7	8	10	9	10	14	15	16	18	31	34
10	4.5	7	9	9	11	12	13	15	17.5	19	23	26	32	35	44
20	6	8	10	10	12	13	15	17	19	21	26	31	35	39	45
30	7	9	10.5	11	13	14.5	16	18	20	23	28	34	38	41	46
40	7.5	9.5	11	12	14	15	17	19	21	25	30	36	40	45	48
50	8	10	11.5	13	15	16	18	20	23	26	32	38	43	46.5	49
60	8.75	10.5	12	13.5	15	17	19	21	24	28	35	40	45	48	50
70	9	11	12.5	14	16	18	20	22	26	30	38.5	42	46	49	54
80	9.5	11.5	13	15.5	17.5	19	21	24	28	32	39	45	48	52	57
90	11	13	14.5	17	19	20	23	26	31	36	45	48	51.5	58	59
100	15.5	16.5	20	22	25	26.5	26.5	32	50	51	61	79	67	68	67

MALES

TABLE VI.—THE SMEDLEY PERCENTILES OF VITAL CAPACITY EXPRESSED IN CUBIC CENTIMETRES

PER-CENTILES	6TH	7TH	8TH	9TH	10TH	11TH	12TH	13TH	14TH	15TH	16TH	17TH	18TH	19TH	ADULT
0	650	700	700	800	850	900	1100	1150	1500	1200	1400	1800	1750	2450	2950
10	750	900	1000	1100	1225	1350	1400	1600	1800	1850	2150	2400	2900	3200	3300
20	800	975	1100	1200	1300	1450	1550	1700	1900	2100	2350	2800	3125	3350	3700
30	850	1000	1150	1250	1400	1500	1650	1800	2000	2200	2500	2950	3250	3500	3900
40	900	1075	1200	1300	1450	1600	1725	1875	2100	2300	2700	3150	3450	3600	4000
50	900	1100	1225	1350	1500	1650	1800	1950	2200	2450	2800	3300	3575	3850	4100
60	950	1125	1300	1400	1600	1700	1875	2025	2300	2575	3000	3500	3700	3975	4150
70	1000	1200	1300	1500	1625	1800	1975	2100	2350	2750	3200	3600	3850	4125	4320
80	1000	1225	1400	1575	1700	1900	2050	2225	2500	2950	3400	3800	4000	4200	4480
90	1075	1325	1475	1700	1850	2000	2200	2400	2750	3300	3650	4200	4350	4750	4840
100	1250	1600	1750	2100	2250	2750	3000	3150	4200	4400	4550	5100	5000	5000	5500

FEMALES

TABLE VII.—THE BERRY-PORTEUS PERCENTILES OF BRAIN CAPACITY EXPRESSED IN CUBIC CENTIMETRES.

PER-CENTILES	7TH	8TH	9TH	10TH	11TH	12TH	13TH	14TH	15TH	16TH	17TH	18TH	19TH	ADULT
0	1054	1044	1070	1118	1080	1077	1100	1097	1161	1141	1126	1151	1178	1192
10	1118	1136	1130	1160	1165	1167	1202	1214	1236	1235	1233	1244	1264	1253
20	1137	1158	1155	1185	1195	1193	1233	1247	1254	1269	1266	1265	1289	1289
30	1155	1169	1182	1213	1213	1218	1252	1269	1270	1291	1294	1286	1310	1322
40	1177	1195	1201	1225	1237	1246	1268	1283	1290	1307	1311	1303	1326	1333
50	1193	1207	1230	1239	1255	1263	1290	1298	1308	1326	1328	1328	1349	1351
60	1209	1221	1240	1259	1266	1278	1306	1324	1332	1345	1348	1347	1374	1368
70	1230	1237	1258	1267	1281	1303	1326	1339	1358	1362	1363	1371	1381	1380
80	1251	1251	1271	1287	1324	1335	1348	1355	1382	1383	1393	1406	1408	1405
90	1284	1279	1302	1309	1368	1381	1384	1387	1428	1427	1425	1436	1427	1453
100	1378	1367	1442	1542	1502	1473	1508	1534	1526	1588	1542	1598	1575	1606

FEMALES

TABLE VIII.—THE SMEDLEY PERCENTILES OF STANDING STATURE EXPRESSED IN MILLIMETRES.

PER-CENTILES	6TH	7TH	8TH	9TH	10TH	11TH	12TH	13TH	14TH	15TH	16TH	17TH	18TH	19TH	ADULT
0	937	959	975	1052	1073	1157	1172	1216	1300	1250	1391	1365	1438	1385	1328
10	1001	1065	1113	1165	1209	1248	1297	1361	1413	1481	1503	1516	1523	1527	1540
20	1022	1088	1134	1188	1235	1279	1329	1388	1448	1508	1529	1546	1549	1554	1562
30	1042	1101	1152	1205	1252	1295	1349	1413	1479	1530	1547	1560	1568	1572	1585
40	1055	1114	1170	1221	1270	1307	1367	1431	1498	1551	1561	1580	1582	1589	1597
50	1067	1125	1180	1233	1283	1326	1388	1450	1519	1565	1574	1593	1598	1600	1609
60	1080	1136	1190	1245	1296	1342	1405	1474	1540	1581	1590	1604	1610	1612	1621
70	1091	1152	1202	1257	1311	1359	1420	1492	1558	1596	1605	1622	1624	1628	1628
80	1115	1168	1220	1274	1323	1382	1443	1514	1578	1617	1620	1636	1644	1649	1650
90	1137	1191	1241	1300	1356	1411	1487	1549	1602	1640	1645	1663	1668	1676	1674
100	1184	1282	1341	1408	1436	1577	1576	1654	1718	1714	1737	1785	1790	1771	1778

FEMALES

TABLE IX.—THE SMEDLEY PERCENTILES OF SITTING STATURE EXPRESSED IN MILLIMETRES.

PER-CENTILES	6TH	7TH	8TH	9TH	10TH	11TH	12TH	13TH	14TH	15TH	16TH	17TH	18TH	19TH	ADULT
0	533	556	585	603	613	630	646	662	683	681	660	643	777	743	697
10	572	597	620	642	659	673	695	715	746	779	801	813	821	825	822
20	584	610	632	653	670	690	709	735	764	800	814	827	830	833	838
30	591	617	639	660	680	695	718	746	777	814	823	837	837	842	845
40	597	623	646	667	686	703	730	757	788	823	831	845	844	849	851
50	602	629	653	673	692	710	737	765	798	832	840	850	852	856	858
60	610	635	659	678	700	717	745	777	812	837	847	859	860	864	865
70	616	644	665	685	706	724	753	787	824	845	856	866	871	869	872
80	624	654	673	693	715	735	763	800	832	856	865	876	879	876	882
06 —	631	664	682	704	729	750	784	814	849	870	876	889	890	892	895
—0 1 0	662	699	719	757	798	806	855	866	912	915	919	946	945	937	953

FEMALES

TABLE X.—THE SMEDLEY PERCENTILES OF BODILY WEIGHT EXPRESSED IN KILOGRAMMES.

PER- CEN- TILES	6TH	7TH	8TH	9TH	10TH	11TH	12TH	13TH	14TH	15TH	16TH	17TH	18TH	19TH	ADULT
0	13.300	13.850	15.350	17.175	19.150	19.300	21.000	21.450	23.400	29.225	30.975	33.900	34.200	35.075	30.000
10	15.200	17.200	18.550	20.700	22.710	24.000	26.625	29.500	32.800	37.675	41.250	43.685	44.100	46.100	45.812
20	16.000	18.225	19.800	21.550	23.790	25.550	28.300	31.200	35.500	40.700	43.300	46.160	46.460	48.100	47.600
30	16.625	18.850	20.425	22.400	24.600	26.550	29.287	32.775	37.200	43.050	45.500	47.630	48.365	49.400	49.300
40	17.150	19.450	21.025	23.050	25.580	27.775	30.350	34.750	39.200	44.800	47.300	49.375	49.460	50.660	50.900
50	17.850	19.900	21.675	23.800	26.340	28.665	31.300	36.300	41.000	46.300	48.700	51.150	50.960	52.050	53.000
60	18.400	20.500	22.375	24.400	27.135	29.750	32.560	38.050	42.950	48.125	50.150	52.790	52.390	53.480	54.500
70	18.975	21.325	23.000	25.300	28.120	31.200	34.566	40.000	45.000	49.375	52.075	54.525	54.410	55.200	56.000
80	19.800	21.950	23.900	26.150	29.105	32.150	36.290	41.925	47.650	52.000	53.800	56.540	56.600	57.075	58.000
90	20.600	23.050	25.250	27.700	31.040	34.700	38.825	45.150	51.500	55.600	57.400	60.415	59.735	59.800	62.025
100	23.600	29.250	31.800	41.175	41.550	58.225	55.600	79.000	78.000	74.125	81.350	91.775	75.600	82.150	76.850

FEMALES

TABLE XI.—THE SMEDLEY PERCENTILES OF RIGHT AND LEFT GRIP
EXPRESSED IN KILOGRAMMES.

RIGHT GRIP																
<i>Per- cen- tiles</i>	<i>6th</i>	<i>7th</i>	<i>8th</i>	<i>9th</i>	<i>10th</i>	<i>11th</i>	<i>12th</i>	<i>13th</i>	<i>14th</i>	<i>15th</i>	<i>16th</i>	<i>17th</i>	<i>18th</i>	<i>19th</i>	<i>Adult</i>	
0	3	4	5	6	7	8	8	10	10	14	12	18	14	17	18	
10	5	7	8	9	10	11	12	14.75	17	19	21	23	24	25	28	
20	6	8	9	10	11	12	14	16	18.5	21	23	25	25.5	27	30	
30	6.5	8.5	10	10.5	12	13	15	17	20	22	25	26.75	27.5	29	31	
40	7	9	10	11	13	14	16	18	21	24	26.5	28	29	30	32	
50	7.5	9.5	11	12	13	15	17	19	22	25	28	29	30	31	33	
60	8	10	11	12.5	14	15.5	18	20	23.5	27	29	30	31	32	34	
70	8.5	10	12	13	15	16	19	21	25	28	30	31	32.5	34	35	
80	9	11	12.5	14	15.5	17	20	23	27	30	31	33	34	35	36	
90	10	12	14	15	17	19.5	21.5	25	30	32	33	35	37	38	38	
100	13	15.5	16	20	24	32	27	34.5	45	38	47	48	45	48	44	

LEFT GRIP																
<i>Per- cen- tiles</i>	<i>6th</i>	<i>7th</i>	<i>8th</i>	<i>9th</i>	<i>10th</i>	<i>11th</i>	<i>12th</i>	<i>13th</i>	<i>14th</i>	<i>15th</i>	<i>16th</i>	<i>17th</i>	<i>18th</i>	<i>19th</i>	<i>Adult</i>	
0	2	4	4	5	6	6	8	7	9	12	10	15	12.5	16	19	
10	4	6.5	7.5	8	9	10	11	13	15	18	20	21.5	21.5	23	25	
20	5	7	8	9	10	11	13	14.5	17	19	21	23	23	25	27	
30	6	8	9	9.5	11	12	14	15	18	21	22	25	25	26	28	
40	6.5	8	9.5	10	12	13	15	17	20	22	24	26	26	27.5	30	
50	7	9	10	11	12.5	14	15.5	17.5	21	23	25	27	27.5	29	30	
60	7	9	10.5	11.5	13	14.5	17	19	22	25	27	28	29	30	31	
70	8	10	11	12	14	15	18	20	24	26	28	29	30	31	32	
80	8.5	10	12	13	14.5	16	19	22	25	27.5	29.5	31	31.5	32	34	
90	9.5	11	13	14	16	18	21	24	27.5	30	31	33	33.25	34	37	
100	11.5	15	16	19	22.5	31	25	33.5	40	39.5	47	47	42	47	46	

FEMALES

TABLE XII.—THE SMEDLEY PERCENTILES OF VITAL CAPACITY EXPRESSED IN CUBIC CENTIMETERS.

PER-CENTILES	6TH	7TH	8TH	9TH	10TH	11TH	12TH	13TH	14TH	15TH	16TH	17TH	18TH	19TH	ADULT
0	600	600	750	500	800	800	1000	800	1100	1350	1450	1350	1250	1550	1300
10	700	800	900	950	1100	1200	1300	1400	1325	1700	1800	1900	1900	2025	2250
20	775	850	975	1000	1200	1300	1400	1500	1650	1800	1950	2000	2050	2150	2300
30	800	900	1000	1100	1200	1325	1450	1660	1775	1927	2050	2100	2150	2300	2400
40	800	950	1050	1150	1300	1400	1500	1675	1850	2000	2150	2200	2250	2400	2500
50	850	1000	1100	1200	1325	1450	1600	1750	1925	2100	2225	2300	2350	2425	2550
60	900	1050	1150	1250	1400	1500	1650	1825	2000	2200	2300	2400	2425	2500	2600
70	900	1100	1200	1300	1450	1550	1700	1950	2125	2300	2400	2500	2500	2600	2700
80	950	1175	1250	1350	1500	1650	1800	2025	2250	2400	2500	2600	2600	2700	2800
90	975	1275	1300	1450	1600	1775	1950	2200	2400	2600	2650	2725	2825	2900	2900
100	1150	1400	1650	1800	2100	2150	2400	2950	3050	3200	3400	3500	3500	3675	3600

TABLE XIII.—THE BINET INTELLIGENCE QUOTIENTS EXPRESSED IN PERCENTILES.
For All Ages and Both Sexes.

PERCENTILES	0	10	20	30	40	50	60	70	80	90	100
Intelligence Quotients	30	70	80	87	92	97	101	105	111	117	150

TABLE XIV.—THE PORTEUS INTELLIGENCE QUOTIENTS EXPRESSED IN PERCENTILES.
For All Ages and Both Sexes.

PERCENTILES	0	10	20	30	40	50	60	70	80	90	100
Intelligence Quotients	48	79	85	90	94	97	101	105	112	120	174

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